FINAL FOCUSED FEASIBILITY STUDY
FOR GROUNDWATER
ALASKA REAL ESTATE PARKING LOT
ANCHORAGE, ALASKA

ADEC SPAR TERM CONTRACT #18-8036-13
NOVEMBER 11, 2014

Prepared For:

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APPROVAL PAGE

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TABLE OF CONTENTS

APPROVAL PAGE ... **i**
ACRONYMS AND ABBREVIATIONS ... **vii**
EXECUTIVE SUMMARY ... **ix**
1.0 PURPOSE ... **1**
2.0 SITE BACKGROUND ... **3**
2.1 Responsible Party ... 3
2.2 Community Relations ... 3
2.3 Investigation Summary ... 4
2.3.1 1993 Phase I Environmental Site Assessment ... 4
2.3.2 1997 Phase II Environmental Site Assessment ... 4
2.3.3 2004 Phase II Environmental Site Assessment ... 5
2.3.4 2005 Phase II Environmental Site Assessment ... 5
2.3.5 2007 Additional Site Assessment ... 6
2.3.6 2008 Site Characterization Investigation ... 6
2.3.7 2008 Supplemental Groundwater Investigation ... 6
2.3.8 2009-2010 Vapor Intrusion Assessment ... 7
2.3.9 2011 EPA Preliminary Assessment ... 8
2.3.10 2011 Site Characterization Investigation ... 8
2.3.11 2012 EPA Site Inspection ... 8
2.3.12 2014 Focused Groundwater Study ... 9
3.0 PHYSICAL CHARACTERISTICS ... **11**
3.1 Geologic Setting ... 11
3.1.1 Regional Surficial Geology ... 11
3.1.2 Local Surficial Geology ... 11
3.1.3 Total Organic Carbon Data ... 12
3.2 Hydrogeology ... 12
3.2.1 Regional Hydrogeology ... 12
3.2.2 Groundwater Elevation and Horizontal Groundwater Flow ... 12
3.2.3 Vertical Groundwater Flow ... 13
3.2.4 Hydraulic Conductivity and Seepage Velocity ... 13
4.0 GROUNDWATER CHARACTERIZATION ... **15**
4.1 Nature ... 15
4.2 Trend ... 15
4.3 Extent – Horizontal Delineation ... 15
4.4 Extent – Vertical Delineation ... 16
4.5 Extent – Dissolved-Phase Contaminant Mass ... 16
4.6 Data Gap Summary ... 16
5.0 CONCEPTUAL SITE MODEL – GROUNDWATER ... **17**
5.1 Sources ... 17
5.2 Contaminants of Potential Concern ... 17
5.3 Potential Migration Pathways ... 17
5.4 Potential Exposure Routes ... 18
5.5 Potential Receptors ... 18
6.0 GROUNDWATER REMEDIAL ACTION OBJECTIVES ... **19**

7.0 GROUNDWATER REMEDIAL ALTERNATIVES 21
7.1 General Assumptions for All Alternatives (except No Action) 21
7.1.1 Vapor Intrusion Mitigation 21
7.1.2 Institutional Controls 21
7.1.3 Cost Estimating 21
7.1.4 Data Gaps 22
7.2 Description of Alternatives 22
7.2.1 GW-1: No Action 22
7.2.2 GW-2: Monitored Natural Attenuation 22
7.2.2.1 Biological Degradation of PCE 23
7.2.2.2 MNA Considerations 24
7.2.2.3 Assumptions for Alternative GW-2 25
7.2.3 GW-3: In-Situ Chemical Oxidation (ISCO) 25
7.2.3.1 ISCO Considerations 25
7.2.3.2 Assumptions for Alternative GW-3 26
7.2.4 GW-4: Enhanced Reductive Dechlorination (ERD) 27
7.2.4.1 ERD Considerations 27
7.2.4.2 Assumptions for Alternative GW-4 28
7.2.5 GW-5: Permeable Reactive Barrier (PRB) 29
7.2.5.1 Permeable Reactive Barrier Considerations 29
7.2.5.2 Assumptions for Alternative GW-5 30
8.0 SUMMARY OF COMPARATIVE ANALYSIS OF ALTERNATIVES 33
8.1 Evaluation Criteria 33
8.2 Comparative Analysis of Alternatives 34
8.3 Comparison of Groundwater Alternatives 34
8.3.1 Threshold Criteria 34
8.3.1.1 Protection of Human Health and the Environment 34
8.3.1.2 Compliance with Regulations 35
8.3.2 Balancing Criteria 35
8.3.2.1 Long-Term Effectiveness 35
8.3.2.2 Reduction in Toxicity, Mobility, and Volume through Treatment 36
8.3.2.3 Short-Term Effectiveness 37
8.3.2.4 Implementability 37
8.3.2.5 Cost 38
8.4 Preferred Alternatives 38
9.0 REFERENCES 41

TABLES – IN TEXT

Table 2-1: ADEC Changes to Residential Target Levels for Air 4
Table 3-1: Physical Aquifer Parameters 13
Table 6-1: Groundwater ARARs 19
Table 7-1: MNA Parameter Results 24
Table 8-1: Cost Comparison 38
Table 8-2: Alternative Comparison 39

TABLES – APPENDED

Table 1 Historic Groundwater Sampling Results

FIGURES

Figure 1 State and Site Vicinity
Figure 2 Anchorage Parcels
Figure 3 Site Map
Figure 4 Groundwater Plume
Figure 5 Section Lines
Figure 6 Cross Section A-A’
Figure 7 Cross Section B-B’
Figure 8 ISCO/ERD Injection Areas
Figure 9 PRB Installation Areas

APPENDICES

Appendix A Cost Estimates

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ACRONYMS AND ABBREVIATIONS

#/L..................enumeration per liter
AAC...............Alaska Administrative Code
ADEC............Alaska Department of Environmental Conservation
Ahtna.............Ahtna Engineering Services, LLC
ARAR ....applicable and relevant regulations
ARRC............Alaska Railroad Corporation
bgs..................below ground surface
CERCLA........Comprehensive Environmental Response, Compensation, and Liability Act
CFR................Code of Federal Regulations
COPC............contaminants of potential concern
CSM...............conceptual site model
DCE................dichloroethene
Dhc.................dehalococcoides
DNAPL..........dense, non-aqueous phase liquid
DO..................dissolved oxygen
DRO...............diesel-range organics
E&E................Ecology and Environment
EPA................Environmental Protection Agency
ERD................enhanced reductive dechlorination
ESA................environmental site assessment
EVO...............emulsified vegetable oil
FFS.................focused feasibility study
f_{oc}....................fraction of organic carbon
GRO...............gasoline-range organics
IC....................institutional control
ISCO ....in-situ chemical oxidation
kg/L................kilograms per liter
lbs/ft^3..............pounds per cubic foot
LTM...............long-term monitoring
µg/kg.............micrograms per kilogram
µg/L................micrograms per liter
MCL...............maximum contaminant level
mg/kg.............milligrams per kilogram
mg/L...............milligrams per liter
ML&P............Municipal Light and Power
MNA.............monitored natural attenuation
mV..................millivolt
ND..................non-detect
OASIS............OASIS Environmental, Inc.
OM&M..........operations, maintenance, and monitoring
ORP................oxidation-reduction potential
PCE................tetrachloroethene
PRB................permeable reactive barrier
PRP................potentially responsible party

RAO ....remedial action objective
SMD...............submembrane depressurization
TCE................trichloroethene
TOC................total organic carbon
UST................underground storage tank
VC..................vinyl chloride
VOC ....volatile organic compounds
USCS..............Unified Soil Classification System
ZVI.................zero-valent iron

EXECUTIVE SUMMARY

This focused feasibility study (FFS) was prepared to evaluate and compare remedial options for treatment contamination in groundwater at the Alaska Real Estate Parking Lot source area. Groundwater is primarily contaminated by the chlorinated solvent tetrachloroethene (PCE) related to dry cleaning operations conducted at the site in the 1960s. Soil contamination has also been documented at the site, but is not addressed as part of this FFS.

The primary risks associated with this site, based on a conceptual site model, are the inhalation of indoor air at nearby residences, and ingestion of groundwater and/or surface water. Indoor air at four nearby residences has been documented to be impacted at concentration greater than target levels set by the Alaska Department of Environmental Conservation. Efforts to mitigate the vapors have not been successful to date.

Five alternatives were evaluated and compared as part of this FFS, listed below.

- Alternative GW-1: No Action
- Alternative GW-2: Monitored Natural Attenuation (MNA) with Long-Term Monitoring (LTM)
- Alternative GW-3: In-Situ Chemical Oxidation (ISCO)
- Alternative GW-4: Enhanced Reductive Dechlorination (ERD)
- Alternative GW-5: Permeable Reactive Barrier (PRB)

The alternatives were evaluated against the nine criteria described in 40 CFR 300.430(e)(9)(iii) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Results of the comparative analysis are summarized below in Table E-1. A numerical scoring scheme was used for evaluating the five balancing criteria. Each alternative was assigned a numerical score between 0 (worst) and 5 (best) for each criterion to reflect the expected performance of the alternative. The scores have no independent value; they are only meaningful when compared among the different alternatives.

Based on the analysis, two alternatives, GW-3 (ISCO) and GW-4 (ERD) scored the highest and are similar in effectiveness, cost, and total score. To determine which approach to take, pilot studies and/or bench-scale testing must be completed to test oxidants and amendments at the site and determine which would be most successful with the site conditions. Both would be implemented in a similar manner of injection wells and repeat injections to ensure sufficient addition to treat the source area.

TABLE E-1: ALTERNATIVE COMPARISON

Remedial Alternative		Protection of Human Health and Environment	Compliance with ARARs	Long-Term Effectiveness	Reduction in Toxicity, Mobility, and Volume through Treatment	Short-Term Effectiveness	Implementability	Cost Score	Effectiveness Total	Total Score
GW-1	No Action	No	No	0	0	0	5	5	0	10.0
GW-2	MNA	Yes	Yes	1	1	2	4	2.9	1.3	10.9
GW-3	ISCO	Yes	Yes	3.5	4	3.5	2	0.2	3.7	13.2
GW-4	ERD	Yes	Yes	4	3.5	3.5	2	0	3.7	13.0
GW-5	PRB	Yes	Yes	3	3	3.5	2	0.6	3.2	12.1

1.0 PURPOSE

The purpose of this focused feasibility study (FFS) is to evaluate remedial alternatives for addressing contaminated groundwater at the Alaska Real Estate Parking Lot site located in Anchorage, Alaska (Figure 1). Groundwater at the Alaska Real Estate Parking Lot site is contaminated by the chlorinated solvent tetrachloroethene (PCE) related to dry cleaning operations conducted at the site in the 1960s and potentially 1950s. Groundwater located downgradient of the site is contaminated by the degradation products of PCE including trichloroethene (TCE), the isomers of dichloroethene (DCE), and vinyl chloride (VC). This contamination has resulted in VOC concentrations exceeding the Alaska Department of Environmental Conservation (ADEC) 18 Alaska Administrative Code (AAC) 75 cleanup levels for groundwater, the 18 AAC 80 maximum contaminant levels (MCLs) for drinking water, and the target levels for indoor air set out in the Vapor Intrusion Guidance (ADEC, 2012b). Note that soil contamination has also been documented at the site, but will not be addressed as part of this FFS.

No remedial actions have been taken to date to reduce groundwater contamination, which would likely have the effect of reducing indoor air concentrations.

Two remedial or protective actions have been taken at the site to prevent indoor air impacts to residents in four buildings located near the site. In summer 2009, submembrane depressurization (SMD) systems were installed in the crawl spaces for the North and South Duplexes at 736 East Third Avenue by the building owner (OASIS, 2010b). PCE concentrations were reduced, but an inspection of the systems conducted in November 2010 found that a foundation slab in the North Duplex was not being depressurized (ADEC, 2014b). Subsequent indoor air sampling showed that the concentrations were still greater than the target levels. In summer 2013, the Environmental Protection Agency (EPA) and ADEC met to discuss mitigating indoor air vapor concentrations to reduce risk to residents. In May 2014, passive vapor intrusion mitigation systems were installed in the North and South Duplexes at 736 East Third Avenue, the house at 710 East Third Avenue, and the house at 720 East Third Avenue. Pre- and post-mitigation sampling events of indoor air showed that concentrations of PCE remained greater than the target level of 42 $\mu g/m^3$ in the North Duplex and the house at 720 East Third Avenue (E&E, 2014). Fans were installed at the two buildings in early October 2014 to convert the passive systems to active systems. Indoor air sampling is anticipated to occur in late October 2014 to determine whether the active systems are mitigation vapor intrusion.

This FFS presents a summary of the historical analytical results for the site, a discussion of the nature and extent of groundwater contamination, five remedial alternatives for addressing groundwater contamination, and a comparative analysis of the alternatives. The comparative analysis is presented in tabular form to aid in decision making to determine the preferred alternative.

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2.0 SITE BACKGROUND

The Alaska Real Estate Parking Lot property consists of Lots 8A – 12, Block 26A East Addition located at the northeast corner of the Fourth Avenue and Gambell Street intersection in Anchorage, Alaska, as shown on Figure 2. The property is owned by Fourth Avenue and Gambell Associates LLC. The subject property was formerly occupied by a variety of businesses, including New Method Cleaners from approximately 1955 until the 1960s, C&K Cleaners (which was a dry cleaner) from approximately 1968 through 1970, and Northern Commercial (NC) Tire Center from 1976 to 1978 which was the last occupant of the last building on the eastern portion of the site prior to being demolished in 1978. The property has since served as a parking lot. The approximate locations of the former businesses are shown on Figure 3.

The property includes approximately 40,600 square feet of land and the immediate vicinity is generally flat at approximately 110 feet above mean sea level. The surrounding area has a gentle slope to the north towards the Ship Creek drainage at which point a steep drop-off in elevation occurs.

Presently the site is a predominately undeveloped and unpaved area that is used for parking. A communications tower/antennae located at the south east corner of the property and owned by Alaska Communications is the only other improvement currently located on the site.

Property east, south, and west of the site is primarily retail and commercial including a restaurant (Burger Jim, to the south), auto shop (Downtown Auto Repair to the west), printing facility (PIP Printing to the east), and church (Native Baptist Church to the east). New construction of a building to the east of the site was completed in summer 2014; its purpose is not presently known. The property directly north of the site is residential with two single residences and two duplex residences. Beyond Third Avenue to the north is the former Alaska Native Hospital property, which is now vacant and has no structures. The site vicinity and nearby buildings is shown on Figure 3.

2.1 Responsible Party

The property is owned by Fourth and Gambell LLC. In June 2006, ADEC issued a potentially responsible party (PRP) letter to Paul Maney of Alaskan Real Estate, Inc. the property owner at the time. In January 2007, ADEC issued a PRP letter to Skinner Corporation. ADEC assumed the lead role on the project in June 2008 following Fourth Avenue and Gambell Associates LLC indication that they were unable to fund any additional investigations. In January 2014, EPA sent a Notice of Potential Liability For Removal letter to Skinner Corporation.

2.2 Community Relations

The owners of the four residences north of the Alaska Real Estate Parking Lot with indoor air known to be impacted by PCE were originally notified of the risks in 2009 after the initial assessment. ADEC encouraged the owners to install mitigation systems to mitigate risk. The owners have been in communication with ADEC and EPA.

2.3 Investigation Summary

Site investigation work has been performed at the site since 1993, as summarized in the following sections. Historic groundwater analytical data are tabulated in appended Table 1. Note that the ADEC target levels for indoor air and soil gas have changed over the course of this project. Samples that are reported in historic reports to exceed target levels may no longer exceed the current target levels. Table 2-1 shows the change in target levels.

TABLE 2-1: ADEC CHANGES TO RESIDENTIAL TARGET LEVELS FOR AIR

Compound	Target Level for Residential Shallow Soil Gas ($\mu g/m^3$)		Target Level for Residential Indoor Air ($\mu g/m^3$)	
	Pre-2012	Post-2012	Pre-2012	Post-2012
PCE	40	420	4.1	42
TCE	2.2	21	0.22	2.1
cis-DCE	370	73	37	7.3
trans-DCE	630	630	63	63
Vinyl Chloride	8.1	16	0.81	1.6

2.3.1 1993 Phase I Environmental Site Assessment

A Phase I Environmental Site Assessment (ESA) was conducted in 1993 that identified the operation of a C&K Cleaners from 1968 to 1970 and a NC Tire Center from 1976 to 1978. C&K Cleaners appears to have been located on the western side of the property, and NC Tire Center appears to have been located on the eastern side of the property. The Phase I site reconnaissance indicated that an underground storage tank (UST) vent pipe was visible on the property. All buildings were removed from the site in 1978 and the site then served as a parking lot (EnviroAmerica, 1993).

2.3.2 1997 Phase II Environmental Site Assessment

The findings of the 1997 Phase II ESA indicated that areas of contaminated soil and groundwater were identified on the subject property. The two main areas of interest were located in the western portion of the subject property, where the former dry cleaner building was located, and in the northeastern area of the property, where the former NC Tire Facility was located.

Three trenches dug near the former C&K Cleaners unearthed a log crib and four empty drums marked for use in dry cleaning. A soil sample collected from the drum area at 7 feet below ground surface (bgs) had a concentration of PCE of 3.2 milligrams per kilogram (mg/kg) and one soil sample from the log crib area, collected at 12 feet bgs, contained 1.0 mg/kg of PCE.

Seven hydraulic lifts, associated piping, sumps, a UST, and a log crib were also identified near the former NC Tire Center. Three soil samples collected near the log crib had concentrations of PCE, ethylbenzene, toluene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, arsenic, barium, cadmium, and chromium greater than ADEC soil cleanup levels.

Three monitoring wells, EPM-1/MW-1, EPM-2, and EPM-3, were installed. Groundwater samples were collected from each well and analyzed for volatile organic compounds (VOCs), metals, and petroleum hydrocarbons. No VOCs were detected in EPM-2 and EPM-3. The concentration of PCE in EPM-1/MW-1 was 4.25 milligrams per liter (mg/L), which is greater than the ADEC cleanup level of 0.005 mg/L (EPMI, 1997). This concentration indicates that PCE was present as a dense, non-aqueous phase liquid (DNAPL) because the concentration is greater than 2.00 mg/L (EPA, 2004).

2.3.3 2004 Phase II Environmental Site Assessment

Another Phase II ESA was performed in August 2004, which included excavation of six test pits, removal of five hydraulic lifts, removal of four USTs (two hydraulic oil [500- and 1,000-gallon] and two heating fuel oil [950- and 1,100-gallon]), and removal of approximately 10 cubic yards of soil contaminated with diesel-range organics (DRO) greater than the ADEC soil cleanup level. The hydraulic lifts and USTs were associated with the former NC Tire Center operation. The contaminated soil came from underneath the hydraulic lifts and USTs and was thermally treated off-site. Concentrations of PCE greater than the ADEC soil cleanup level (1.73 to 4.2 mg/kg) were detected in three of the test pits. These three test pits were located on the western side of the property near the location of the former C&K Cleaners (BGES, 2004a).

Monitoring well EPM-1/MW-1 was sampled in October 2004 at a water depth of approximately 40 feet bgs. The sample was analyzed for VOCs by EPA Method 8260B. The concentration of PCE was 2.28 mg/L, which exceeds the ADEC groundwater cleanup level of 0.005 mg/L. All other compounds were less than laboratory reporting limits. Oxidation reduction potential (ORP) was reported at 300 millivolts (mV; BGES, 2004b).

2.3.4 2005 Phase II Environmental Site Assessment

Three additional monitoring wells, MW-2, MW-3, and MW-4, were installed around the former C&K Cleaners building in March 2005. Soil samples were collected from various intervals during drilling and were analyzed for VOCs. Concentrations of PCE ranged from 2.13 mg/kg in the interval from 36 to 38 feet bgs in MW-4 to 79.5 mg/kg in the interval from 28 to 30 feet bgs in MW-2. All other compounds were less than laboratory reporting limits.

PCE results for groundwater were 1.49 mg/L in EPM-1/MW-1, 0.0707 mg/L in MW-2, 1.79 mg/L in MW-3, and 0.372 mg/L in MW-4. All other compounds in groundwater were less than laboratory reporting limits. The conclusion was made that biodegradation of PCE was not occurring at a significant rate because of a lack of PCE daughter compounds and the oxygenated state of the aquifer (BGES, 2005). However, it should be pointed out that dissolved oxygen (DO) was measured at ground surface in purge water obtained by the use of a bailer, which generally does not provide a representative measurement for DO. Groundwater was calculated to flow northeast at a gradient of approximately 0.01 feet per foot (ADEC, 2014b).

A drinking water well survey was conducted. Five wells were identified from a file search within a quarter-mile of the parking lot; however, none were found during site reconnaissance (ADEC, 2014b).

2.3.5 2007 Additional Site Assessment

Soil was assessed in five shallow soil borings (A, C, D, E, and F) that were drilled to depth of 15 feet bgs and three monitoring wells (MW-5, MW-6, and MW-7) that were installed in 2007. Soil samples were collected from two or three intervals in all eight borings. The levels of PCE in surface soil samples (0 to 2 feet bgs) ranged from 1.27 to 13.2 mg/kg and PCE ranged from 0.865 to 821 mg/kg in the subsurface (over 2 feet bgs) soil samples. Concentrations of PCE exceeded the ADEC cleanup values for migration to groundwater per 18 AAC 75.341 of 0.024 mg/kg in all soil samples. TCE was also detected at concentrations greater than the ADEC cleanup values for migration to groundwater per 18 AAC 75.341 of 0.020 mg/kg in the two soil samples collected from boring D at concentrations of 0.0439 and 0.0352 mg/kg.

Groundwater samples were collected from all new and existing wells. Concentrations of PCE in groundwater exceeded the cleanup level of 0.005 mg/L in all three new wells: 0.523 mg/L in MW-5, 0.822 mg/L in MW-6, and 0.0051 mg/L in MW-7 (BGES, 2007). Groundwater was again found to flow northeast.

2.3.6 2008 Site Characterization Investigation

OASIS Environmental, Inc. (OASIS) performed a site characterization in July 2008. The site characterization included installing and sampling six soil borings (SB-1, SB-2, SB-3, SB-4, SB-5, and SB-6), sampling monitoring wells MW-5 and MW-6, and sampling two temporary wells (SB-1 and SB-2).

Analytical results for soil borings SB-2, SB-3, SB-4, SB-5, and SB-6 indicate an area of PCE-impacted soil that is located north and northeast of the former C&K Cleaners. Contamination is present at ground surface in the areas of SB-2, SB-3, and SB-4, but the significant mass of contamination occurs in a gravelly sand profile that begins around 15 feet bgs and extends to approximately 35 feet bgs. The levels of PCE in soil ranged from 0.26 to 54 mg/kg.

Analytical results from groundwater samples collected at the four wells during this site characterization demonstrate that the PCE exceeds the ADEC cleanup level underneath the entire area of the former C&K Cleaners. The plume appears to extend northeastward, which is the reported direction of local groundwater flow. Based on the elevated PCE concentration in MW-2 (0.115 mg/L) and MW-6 (1.60 mg/L), the plume could possibly extend west of Gambell Street and north of Third Avenue. The absence of PCE or other significant concentrations of VOCs in soil samples and groundwater from the temporary up-gradient well SB-1 indicated that an upgradient source is not believed to be contributing to contamination at the subject site (OASIS, 2008).

2.3.7 2008 Supplemental Groundwater Investigation

In 2008, the EPA hired CH2M Hill and Ecology and Environment (E&E) to evaluate potential upgradient sources of contamination that may be impacting Alaska Railroad Corporation's (ARRCs) Anchorage Terminal Reserve Groundwater Area of Interest GW 2/3 located on the south side of Ship Creek along Ship Creek Avenue and west of Ingra Street. The EPA requested a supplemental groundwater investigation that included installation and sampling of 15 temporary well points and sampling of 13 existing monitoring wells for VOCs, DRO, and gasoline-range organics (GRO). Eight of the temporary well points were located just north of the Alaska Real Estate Parking Lot between 3rd and 1st Avenues (Blocks 35 and 36 East Addition Subdivision) on vacant land where the Alaska Native Hospital was formerly located.

PCE was detected in three of these temporary wells (WP8, WP11, and WP12) at concentrations of 0.14 to 0.62 mg/L. PCE was also detected at a concentration of 0.023 mg/L in an existing monitoring well (MW-28) located at the base of the bluff and downgradient from the three temporary wells. Interestingly MW-28 also contained substantial concentrations of PCE breakdown products including cis-DCE (0.18 mg/L) and VC (0.022 mg/L).

Only trace or non-detectable levels of breakdown products cis-DCE and VC were detected in the plume at the top of the bluff, which suggests that PCE does not significantly biodegrade until the plume is comingled with the petroleum hydrocarbon plume at the base of the bluff (CH2M Hill and E&E, 2008).

The report concluded, and the conclusion subsequently included the ARRC Terminal Reserve Remedial Investigation and Feasibility Study report, that the Alaska Real Estate Parking Lot PCE source was responsible for the VC contamination found at the GW 2/3 area of the ARRC Terminal Reserve.

2.3.8 2009-2010 Vapor Intrusion Assessment

OASIS performed additional site characterization and sampling in 2009 and 2010 with the inclusion of vapor intrusion assessments at four residential buildings located on Lots 1-6, Block 26A East Addition just north of the Alaska Real Estate Parking Lot (710 East Third, 720 East Third, North Duplex, South Duplex). The assessments included the collection of soil gas samples, outdoor air samples outside each building, and the collection of either indoor air or crawl space air samples four times (March 2009, June 2009, February 2010, and May 2010). Analytical results from the four assessments indicated that PCE was present in soil gas at concentrations exceeding the historic ADEC target soil gas level of 40 $\mu g/m^3$ at all four residences for all four sampling events. However, compared to the current target level of 420 $\mu g/m^3$, only the residence at 720 E. Third exceeded the target levels for all four sampling events, and the South Duplex exceeded the target soil gas level only during the two summer sampling events.

In addition, indoor air or crawl space analytical results showed that PCE was present at concentrations greater than the historic ADEC indoor air target level of 4.1 $\mu g/m^3$ at all four residences. However, compared to the current target level of 42 $\mu g/m^3$, only the residence at 720 E. Third and the North Duplex exceeded the target levels. These findings indicated that PCE was present in the residences at concentrations, likely as a result of vapor intrusion (OASIS, 2009).

A passive soil gas survey was also performed for the four-block area between Third and Fourth Avenues and between Gambell and Ingra Streets. The passive soil gas results showed that elevated PCE concentrations occur around the former C&K Cleaners and extend to the four residences. Elevated concentrations of PCE were also detected adjacent to the PIP Printing and First Native Baptist Church buildings, located one block east of the site (OASIS, 2010a).

2.3.9 2011 EPA Preliminary Assessment

E&E conducted a Preliminary Assessment in October 2011 under contract to the EPA. A site visit was conducted and existing information reviewed to evaluate potential receptors. It was noted that several of the wells were damaged and in non-serviceable condition, likely related to a resurfacing of the parking lot with six inches of gravel in July 2011. The report concluded that contamination was present and migrating to the northeast, but the impacts to sensitive environments, Ship Creek, or residents to the northwest of the parking lot are not known (E&E, 2013).

2.3.10 2011 Site Characterization Investigation

In 2011, OASIS evaluated the extent of contamination east of the subject property (i.e., between Fourth and Third Avenues and between Hyder and Ingra Streets). Four soil borings were advanced and converted to monitoring wells (MW-8, MW-9, MW-10, MW-11) and ten soil gas probes were installed on Block 26B, East Addition Subdivision. Soil, groundwater, and soil gas samples were collected and analyzed for VOCs. Analytical results showed that soil, groundwater, and soil gas concentrations were less than ADEC cleanup levels or target criteria for PCE, suggesting that PCE contamination has not migrated east of the Block 26A East Addition Subdivision where the subject property is located (OASIS, 2012).

2.3.11 2012 EPA Site Inspection

In 2012, the EPA contracted E&E to further characterize the source and extent of contamination previously observed at the C&K Cleaners and surrounding locations. E&E advanced 13 soil borings that were sampled at five foot intervals and of which 12 were completed as temporary monitoring wells (BH01GW through BH12MW). Additionally 31 surface soil, 10 soil gas, 12 indoor, 8 outdoor air, and 10 sediment samples were collected and analyzed for VOCs. Electromagnetic and ground penetrating radar was used to locate buried drums and wooden cribs. A brief summary of the investigation work performed at the site is provided below (E&E, 2013).

- Soil samples from several boreholes (BH01, BH02, BH03, BH05, BH07, BH08, and BH09) located near the former C&K Cleaners reported elevated concentration of PCE at varying depths down to 50 feet bgs (maximum depth sampled). The 45-50 feet bgs soil sample from BH11 (located on the former Native Hospital site north of Third Avenue) contained 0.15 mg/kg of PCE.
- PCE was reported in groundwater at concentrations greater than the cleanup level of 0.005 mg/L in eight of the groundwater monitoring wells sampled with PCE concentrations ranging from 0.0078 to 8.5 mg/L. PCE was not observed in the only groundwater sample (BH12) taken north of Third Avenue, but this sample had an elevated reporting limit. No groundwater sample was collected at BH11 but the soil contamination and previous groundwater monitoring results show that PCE is present at this location.
- Four of the indoor air samples showed concentrations exceeding the historic ADEC indoor air target level of 4.1 µg/m^3 in the North and South Duplex buildings.

However, only the North Duplex had samples exceeding the current target level of 42 $\mu g/m^3$.

- Two of the soil samples located near the former C&K Cleaners had PCE concentrations that exceeded the ADEC soil cleanup level of 0.024 mg/kg for migration to groundwater.
- Ten sediment samples collected from along Ship Creek had concentrations that were less than the reporting limit for PCE.

2.3.12 2014 Focused Groundwater Study

Ahtna Engineering Services, LLC (Ahtna) conducted a focused groundwater characterization investigation in May 2014 to assess the status of the PCE plume at the site and delineate the Alaska Real Estate Parking Lot plume from other downgradient plumes. Four soil borings were drilled and converted to monitoring wells (4GMW-12, 4GMW-13, 4GMW-14, and 4GMW-15) to the north and east of the site. Soil samples were not collected; however, Color-Tec screening was conducted and indicated PCE presence in 4GMW-14 and 4GMW-15. Significant petroleum impacts were noted visually and by odor in 4GMW-13, 4GMW-14, and 4GMW-15. A soil sample collected for waste characterization for disposal of soil indicated DRO impacts of 6,100 mg/kg and GRO of 150 mg/kg.

Four wells (EPM-1/MW-1, MW-2, MW-3, MW-4) in the parking lot were decommissioned in place due to permanent non-serviceable damage. Only wells MW-5, MW-6, and MW-7 remain in the source area.

Groundwater samples were collected from the existing monitoring wells near the parking lot (MW-5, MW-6, MW-7), one background well to the east (MW-10), the four new downgradient wells, and four wells downgradient associated with the Municipal Light and Power (ML&P) site and the ARRC site (DPB24, MW12S, MW13, MW28). The samples were analyzed for VOCs, monitored natural attenuation (MNA) parameters, microbial populations of *Dehalococcoides* (*Dhc*), and compound stable isotopes of carbon and chlorine. Additionally, datalogging pressure transducers were deployed in three wells near First Avenue and Ingra Street to evaluate groundwater flow direction downgradient of the site.

Groundwater analytical results indicated that there were likely two sources of PCE in the area. PCE in the parking lot source area remained at elevated concentrations and still showed no daughter products; MNA parameters do not support biological degradation; *Dhc* is not present in the source area; and all lines of evidence indicating that PCE is not biologically degrading. However, results from the downgradient wells indicate the PCE is degrading; TCE, DCE, and VC are all present, MNA parameters suggest conditions supporting of dechlorination, and *Dhc* microbes are present. Previously it was concluded that the PCE is not able to degrade until it reached the petroleum contamination located north of the bluff. However, compound stable isotope analysis results indicated that the isotopes from MW-5 and MW-6 were significantly different from MW-28 located downgradient. This suggests that contamination in this area may be from other sources.

Groundwater flow direction appears to be consistently northeast near the parking lot, but trends due north along Ingra Street and then turns west north of the bluff. Wells 4GMW-12 and 4GMW-13 bound the plume to the east along Ingra Street.

3.0 PHYSICAL CHARACTERISTICS

The following sections detail the physical characteristics of the Alaska Real Estate Parking Lot and surrounding area.

3.1 Geologic Setting

3.1.1 Regional Surficial Geology

The Alaska Real Estate Parking Lot site is located on the southern bluff of Ship Creek. The site is located approximately 1,700 feet south of Ship Creek on a bluff that rises approximately 40 to 50 feet above Ship Creek.

The City of Anchorage is located on a moderately broad lowland bounded on the east by the Chugach Mountains, on the west by Cook Inlet, and by Knik Arm and Turnagain Arm of Cook Inlet to the north and south (respectively). Unconsolidated deposits in this area include glacial, alluvial, colluvial, and lacustrine deposits. The unconsolidated deposits were placed during multiple glacial and non-glacial geologic events, resulting in a complex, vertically discontinuous stratigraphy, measuring from 650 feet thick near Anchorage to only several feet thick along the Chugach Mountains.

The surficial geological conditions primarily consist of quaternary glacial outwash deposits comprised of gravel, sand, silt, and clay. The deposits vary in thickness depending on location but are approximately 50 feet thick along the top of the bluffs adjacent to Ship Creek. These deposits are interfingered with thin silt and fine sand lenses. The entire area is underlain with a layer of poorly permeable silty-clay, known locally as the Bootlegger Cove Formation. The Bootlegger Cove Formation was deposited over older sand, gravel, and glaciofluvial silt which were then subjected to a period of erosion before deposition of the Bootlegger Cove Formation. The cohesive facies of this formation have been referred to as the Bootlegger Cove clay or the “blue clay.” The Bootlegger Cove Formation ranges in thickness from zero up to about 300 feet and averages about 100 to 150 feet.

3.1.2 Local Surficial Geology

The site is located on a gravel parking lot overlying glacial outwash deposits along Ship Creek. Test pit and boring log information for this area indicated that the shallow subsurface soils consist of sandy gravels or gravelly sands in accordance with the Unified Soil Classification System (USCS) to depths of approximately 50 feet where the Bootlegger Cove Formation was encountered.

The sandy gravel and gravelly sand is a gray-brown and poorly sorted. Several 1-inch to 3-inch coal layers were observed between 15 and 40 feet bgs in several of the borings. A gray-brown, well sorted sand, containing no gravel was observed from approximately 30 to 45 feet bgs in all borings across the site. Thin clay layers (0.1 to 1 feet thick) were present in numerous boreholes starting between 44 and 48 feet bgs. The clay is very dense, plastic, and varies in color from yellowish-gray to brick red. No reported grain size classification tests have been performed on any of the subsurface soil samples from the site.

3.1.3 Total Organic Carbon Data

During the 2007 site investigation, eight soil samples were analyzed for total organic carbon (TOC; BGES, 2007). The TOC concentrations ranged from not detected (< 1,000 mg/kg) in two samples to 519,000 mg/kg in a sample at 32.5 to 34.5 feet bgs from MW-7. Presumably this TOC concentration has been impacted by the coal seam layers that are present above and below the sample location.

Assuming that the non-detect TOC concentrations are equal to the detection limit and excluding the highest TOC concentration the average TOC concentration from the remaining seven samples is 5,500 mg/kg or fraction of organic carbon (f_{oc}) of 0.0055.

3.2 Hydrogeology

3.2.1 Regional Hydrogeology

Two primary groundwater aquifers are known to exist in this area. The upper aquifer is unconfined and is mainly a locally continuous sheet of outwash sediments varying from 10 feet to 50 feet in thickness. The lower aquifer is confined and consists of interfingered sands, gravels, and tills that thin and merge with the upper aquifer materials near the Chugach mountain front to the east of Anchorage. The intervening confining unit is a continuous layer of clay and silt known locally as the Bootlegger Cove Formation. This unit grades eastward to tills and till-like deposits and pinches out near the mountain front. The Bootlegger Cove formation was inferred to between approximately 80 and 144 feet thick within the cadastral boundaries of the Alaska Real Estate Parking Lot property. Regionally groundwater in both the confined and unconfined aquifer systems flows in a generally westward direction from the Chugach Mountains to Cook Inlet.

The sand and gravel of the unconfined and confined aquifers are exceptionally permeable. Recharge studies were conducted by temporarily diverting the flow of Ship Creek into storage basins on Fort Richardson. A permeability of 68.6 meters/day (225 feet/day) was calculated from this study (Anderson, 1977).

The mean annual precipitation for Anchorage, Alaska, as measured at Merrill Air Field from November 1997 to December 2008, is 14.78 inches (WRCC, 2014).

3.2.2 Groundwater Elevation and Horizontal Groundwater Flow

The upper unconfined aquifer appears to flow generally toward the north to northeast and then switches to a more northwesterly direction near the base of the bluff until it flows into Ship Creek (E&E, 2013).

Based on the static groundwater measurements taken during the 2008 Area GW 2/3 Supplemental Groundwater Investigation (CH2M Hill and E&E, 2008), the general local groundwater flow direction is toward the northeast (Figure 4). Local variations in the groundwater flow directions are noted with a more northwesterly direction on western portion of the former Native Hospital property, a more northeasterly direction on the eastern portion of the former Native Hospital property, and a westerly direction along the railroad. The groundwater surface elevation in this area roughly mimics the ground surface elevation. A groundwater gradient of approximately 4 feet per 100 feet is present between the site and Ship Creek (i.e., 10 feet of horizontal distance equates to a 0.4 foot change in groundwater elevation). The groundwater gradient is slightly less in the immediate vicinity of the site with a gradient of approximately 1.25 feet per 100 feet (i.e., 10 feet of horizontal distance equates to a 0.125 foot change in groundwater elevation).

3.2.3 Vertical Groundwater Flow

Vertical groundwater gradient has not been evaluated at this site but is expected to be downward in the unconsolidated materials above the Bootlegger Cove Formation.

3.2.4 Hydraulic Conductivity and Seepage Velocity

Grain size classification tests and hydraulic conductivity tests have not been performed at the Alaska Real Estate Parking Lot site. Physical aquifer parameters were obtained from literature and are summarized in Table 3-1.

TABLE 3-1: PHYSICAL AQUIFER PARAMETERS

Soil Type	Hydraulic Conductivity (cm/s)	Dry Bulk Density (g/cm^3)	Total Porosity (η)	Effective Porosity (η)
Sandy Gravel (GW)	0.2	2	0.3	0.25
Slightly Sandy Silt (ML)	1×10^{-4}	1.4	0.45	0.15
Gravelly Sand (SP)	0.05	1.5	0.4	0.25

Key:
Estimated from Freeze and Cherry, 1979 and Wiedemeier et. al, 1999.

The travel speed of dissolved-phase contamination is slower than the travel speed of the water, due to sorption processes slowing the contaminant front. This phenomenon is generally referred to as “retardation” and may be quantified by a retardation coefficient that expresses how much slower a contaminant moves compared to the water. The retardation coefficient for PCE at the Alaska Real Estate Parking Lot site was calculated by the following equation.

EQUATION 1: RETARDATION COEFFICIENT

$$R = 1 + \frac{\rho_b * K_d}{\eta}$$

Where: R = retardation coefficient
ρ_b = dry bulk density (assume 1.7 g/cm^3)
K_d = sorption coefficient (K_{oc}*f_{oc})
K_{oc} = organic carbon coefficient of contaminant (assume 225 [40 CFR 141])
f_{oc} = mass fraction of organic carbon (assume 0.0055)
η = total porosity (assume 0.4)

Based on the assumptions above, the retardation coefficient is 6.9, indicating that the velocity of travel will be impeded by a factor of almost 7 compared to groundwater velocity.

4.0 GROUNDWATER CHARACTERIZATION

The groundwater PCE plume is shown in Figure 4. The characteristics of the PCE groundwater plume are discussed in detail in the following subsections.

Investigations conducted prior to 2014 have generally concluded that the Alaska Real Estate Parking lot PCE-contaminated groundwater has migrated to the northeast in the direction of groundwater flow with little biological degradation, eventually intercepting with petroleum contamination located beyond the bluff. After interception with the petroleum, the plume undergoes biological degradation to the daughter products TCE, DCE, and VC as seen in MW-28. However, data collected during the focused groundwater investigation in 2014 are compelling that while PCE-impacted groundwater from the Alaska Real Estate Parking Lot may be contributing to the concentrations in MW-28, there is likely another source in the downgradient area migrating from the east. For this reason, and because the primary risk exposure is located in the residential area, only the source area of the Alaska Real Estate Parking Lot, located between Third and Fourth Avenues and Gambell and Hyder Streets will be addressed in the FFS.

Figure 5 displays a plan view of monitoring well and soil boring locations along with the locations of cross-section A-A' running along the groundwater flow path and B-B' running perpendicular to the groundwater flow. The cross-sections, presented in Figures 6 and 7 illustrate the groundwater surface.

4.1 Nature

The groundwater plume located near the source area and migrating northeast toward the bluff is primarily comprised of PCE. PCE is detected in groundwater, with the highest concentrations (8,500 micrograms per liter [µg/L]) located with 200 feet downgradient of the former location of C&K Cleaners. As shown on cross section A-A', PCE concentrations range from 18 µg/L upgradient, to 8,500 µg/L in the source area (BH01), to 420 µg/L near the bluff edge (WP12).

The only daughter product detected in the plume at concentrations greater than Table C Groundwater Cleanup Levels is TCE, detected in four temporary monitoring wells and one permanent well located south of the bluff. TCE concentrations ranged from 6 to 11 µg/L.

4.2 Trend

Of the 35 wells located south of the bluff, 22 were temporary and only sampled once. The remaining 13 have only been sampled sporadically and none have sufficient data to conduct a trend analysis. The data are presented in appended Table 1.

4.3 Extent – Horizontal Delineation

Groundwater impacted by PCE at concentrations greater than the ADEC 18 AAC 75.345 Table C cleanup levels has been documented in the area surrounding the former dry cleaner (Figure 4). The plume is delineated in each direction near the source area as follows, generally bounded within one city block (approximately 200,000 square feet):

- To the south by temporary monitoring wells SB-01 (2008) and BK01GW (2013).
- To the west by temporary monitoring well BH04GW (2013).
- To the east by monitoring wells MW-9, MW-10, and MW-11 (2011).
- To the north by temporary monitoring wells WP10, WP13, WP14, WP15 (2008).

However, the plume migrates to the northeast in a narrow path, approximately 300 feet wide and approximately 600 feet towards a steep bluff that drops approximately 80 feet in elevation over 500 feet (0.16 feet/foot). Groundwater flow direction toward the bluff is northeast, at the bluff appears to transition to the north and at the base of the bluff appears to transition to the west. Due to the terrain, there are no monitoring wells located along the bluff face; it is unclear how the plume migrates over and beyond the bluff. PCE, TCE, DCE, VC, and petroleum contamination is detected beyond the bluff, possibly from multiple sources.

The groundwater plume area, not including contamination beyond the bluff, is estimated to cover approximately 380,000 square feet or approximately 8.5 acres. There is uncertainty in the plume size beyond the bluff.

4.4 Extent – Vertical Delineation

The groundwater contaminant plume is illustrated in cross sections A-A’ and B-B’ (Figures 6 and 7). As shown in these figures, a vadose zone of approximately 40 to 45 feet overlies the groundwater saturated interval. The thickness of this saturated interval is poorly defined as most boreholes did not definitively encounter the underlying Bootlegger Cove clay formation. Clay was encountered from 47.5 to 50 feet bgs in BH-03, 46 to 48 feet bgs in BH-04, 45.5 to 50 feet bgs in BH-06, and 45 to 50 feet bgs in BH-08 (E&E, 2013). However other boreholes passed through a 1 to 2 feet thick clay layer and then encountered more sandy material (e.g. BH-05, BH-07, and BH-09).

The Bootlegger Cove clay formation was encountered definitively while drilling downgradient wells 4GMW-13, 4GMW-14, and 4GMW-15 at elevations of 28 feet, 27 feet, and 26 feet, respectively. Due to the presence of the bluff, the bottom elevation of the deepest well in the source area is 51 feet. If it is assumed that the clay formation is present at an elevation of 26 feet in the source area also, the aquifer thickness is approximately 55 feet.

4.5 Extent – Dissolved-Phase Contaminant Mass

Assuming that the aquifer thickness is 55 feet, the area of the plume is 380,000 square feet, the average PCE concentration in the area is 1,000 µg/L (0.018 grams per cubic foot), and the average aquifer porosity is 0.2, conservatively based on a sandy loam, the estimated contaminant mass is approximately 75 kg or 165 pounds.

4.6 Data Gap Summary

The primary data gaps in understanding the groundwater PCE plume are the depth of the Bootlegger Cove clay formation in the source area, the fate of the plume at the bluff located approximately 800 feet north of the source area, and the trend of the plume concentrations over time.

5.0 CONCEPTUAL SITE MODEL – GROUNDWATER

A conceptual site model (CSM) was prepared as part of the Site Characterization Report prepared by OASIS Environmental, Inc. in 2008. Based on the Site Inspection report from February 2013 (E&E, 2013) and the data collected in by Ahtna in 2014, an updated groundwater CSM is provided in the following sections. A risk analysis has not been conducted for this site.

5.1 Sources

Potential sources for the Alaska Real Estate Parking Lot are described in detail in the February 2013 Site Inspection report (E&E, 2013). The sources include a wood crib and associated underground collection sumps located near the former NC Tire Center property, a log crib located near the former C and K Cleaners property, and four buried drums marked for dry cleaning use near the former C and K Cleaners property. Petroleum underground storage tanks and hoists were also located in the area but have been removed and no evidence of petroleum impacts remains. Other sources may have included leaking disposal lines and general housekeeping practices that were common at the time. A secondary source of contamination appears to be PCE-impacted soil in the subsurface at the site.

Evidence found during the focused groundwater characterization in 2014 indicates that a separate source of PCE may be present downgradient of the site north of the bluff. That source is unknown at this time but anticipated to be migrating from the east. This is further described in Section 2.3.12.

5.2 Contaminants of Potential Concern

Contaminants of potential concern (COPCs) based on historic soil, air, sediment, and groundwater sampling in the area are VOCs, specifically PCE and TCE. Daughter products cis-DCE, trans-DCE, and VC and other VOCs have been found in select areas north of the bluff, but are not verified to be solely from the Alaska Real Estate Parking Lot source.

5.3 Potential Migration Pathways

Impacted groundwater has migrated to the northeast and north from the site toward Ingra Street in the upper aquifer at approximately 40 feet bgs that is confined by the Bootlegger Cove clay formation. From groundwater, volatile contamination is likely volatilizing to air (as evidenced by air impacts). Sediment samples collected from Ship Creek indicate that there are no impacts from groundwater to the sediment. VOCs are not typically taken up by biota and so uptake by plants or animals is unlikely.

There is a data gap as to whether the impacted groundwater is flowing to surface water bodies. A surface water body was identified during the 2014 field event and located north of the bluff but south of monitoring well 4GMW-14 and within the fenced area of the former Alaska Native Hospital property. The Ship Creek surface water body is located approximately 1,000 feet north of the bluff.

5.4 Potential Exposure Routes

The area of the groundwater plume is located within the municipal drinking water system, and it appears that no private drinking water wells are located in the area (E&E, 2013). Surface water from Ship Creek is used as a resource for recreation, typically fishing, but not for drinking water in the area downgradient of the site. The surface water body located south of 4GMW-14 is within a fenced area and not likely used; however, it may be an exposure route to wildlife and the area is known to be a heavily-traversed area by the Anchorage homeless population.

5.5 Potential Receptors

Due to the lack of exposure routes, it is not likely there are any receptors to impacted groundwater.

6.0 GROUNDWATER REMEDIAL ACTION OBJECTIVES

The overall objectives of remediation are to ensure that conditions at the site are protective of human health and the environment and to comply with relevant state and federal regulations. Based on the groundwater-specific CSM, the primary threats to human health and the environment are through the groundwater pathway by ingestion of groundwater and through the vapor intrusion pathway by inhalation of indoor air in buildings located at the site. The COPCs are PCE and TCE which are known carcinogens. There is also the potential for the daughter products of PCE and TCE, cis-DCE, trans-DCE, and VC to be present at the site during remedial activities; they are also known carcinogens. This FFS focuses on groundwater contamination in and near the Alaska Real Estate Parking Lot.

The applicable or relevant and appropriate requirements (ARARs) are the following and are summarized in Table 6-1.

- 18 AAC 75.341 Table C Groundwater Cleanup Levels (ADEC, 2012a)
- 18 AAC 80.300 Maximum Contaminant Levels (40 CFR 141.61(a))
- 18 AAC 70.020 Water Quality Criteria
- ADEC Vapor Intrusion Guidance for Contaminated Sites, Appendix G, Groundwater Target Levels
- ADEC Fact Sheet: Additional Information about Exposure to TCE

TABLE 6-1: GROUNDWATER ARARS

Target Media	Groundwater	Drinking Water	Surface Water	Indoor Air
Contaminant	**18 AAC 75.341 Table C Groundwater Cleanup Level (µg/L)**	**18 AAC 80.300 (40 CFR 141.61(a) Maximum Contaminant Level (µg/L)**	**18 AAC 70.020 Water Quality Criteria ^**	**Groundwater Target Level (µg/L)**
Tetrachloroethylene	5	5	-	58
Trichloroethylene	5	5	-	2.5*
cis-1,2-dichloroethylene	70	70	-	44
trans-1,2-dichloroethylene	100	100	-	380
Vinyl chloride	2	2	-	1.4

Note:
^ There are only narrative criteria for surface water.
* Target level based on inhalation from tap water, not volatilization to indoor air from groundwater (ADEC, 2014a)

The primary objective of remedial action (RAOs) at the Alaska Real Estate Parking Lot site are the following.

- Reduce current human health exposure risk to less than the ADEC threshold cancer risk level of 10^{-4} to 10^{-6} and the threshold non-cancer index of 1.
- Protect downgradient surface water from migrating contaminated groundwater. Note that data are lacking to define potential impacts to surface water bodies. Additional site characterization activities are recommended in the future to address these potential impacts.

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7.0 GROUNDWATER REMEDIAL ALTERNATIVES

Five remedial alternatives were evaluated to address treating dissolved-phase PCE contamination in groundwater. The alternatives are listed below and discussed in the following sections.

- Alternative GW-1: No Action
- Alternative GW-2: MNA with Long-Term Monitoring (LTM)
- Alternative GW-3: In-Situ Chemical Oxidation (ISCO)
- Alternative GW-4: Enhanced Reductive Dechlorination (ERD)
- Alternative GW-5: Permeable Reactive Barrier (PRB)

7.1 General Assumptions for All Alternatives (except No Action)

7.1.1 Vapor Intrusion Mitigation

The primary current human health risk at this site is indoor air inhalation due to vapor intrusion into the homes located adjacent to the Alaska Real Estate Parking Lot. Therefore, operation of vapor intrusion mitigation systems for nearby buildings and residences is assumed for protection of human health until groundwater RAOs are met or the vapor intrusion risk has been mitigated.

It should be noted that while even after the target levels for groundwater are reached, it is possible that the vapor intrusion pathway may persist due to the presence of impacted soil in the vadose zone near the residences. It may be necessary to remediate soil impacts to ensure that indoor air contamination is mitigated.

7.1.2 Institutional Controls

All of the groundwater alternatives will have an institutional control (IC) component to protect human health until RAOs are met. In general, ICs include engineering controls, such as fences, and document controls, such as deed restrictions, to restrict site activities that could pose a potential threat to human health. The ICs anticipated for the Alaska Real Estate Parking Lot site include restricting the installation of drinking water wells in the vicinity of the groundwater plume.

The formality and duration of ICs will vary by alternative, depending on its remedial timeframe. The costs for establishing ICs are included in the cost analysis.

7.1.3 Cost Estimating

Costs for each alternative were prepared consistent with the FS Cost Estimating Guidance (EPA, 2000). The detailed cost estimates include capital costs, operating, maintenance, and monitoring (OM&M) costs, contingencies, and present value analysis to allow direct comparison of alternatives with different remedial timeframes. Present value costs were calculated using a 7 percent discount rate, as recommended for non-federal-government-funded projects in the EPA guidance. Although detailed cost estimates were prepared for each alternative, the cost estimate accuracy is considered to be more similar to a screening-level analysis with costs presented in a range of -50% to +100%, which is the high end of the uncertainty range shown in Exhibit 2-3 of the guidance.

7.1.4 Data Gaps

As discussed previously, there are still data gaps to be addressed before implementing groundwater remediation at this site. The total depth of contamination is unknown across much of the site. Hydrogeological and geotechnical data are very limited with regards to permeability or hydraulic conductivity. The nature and extent of contamination in groundwater has been incompletely characterized to the north of the bluff. Only limited TOC data have been collected from the site.

Additional characterization and a pilot test (or tests) of the most promising alternative(s) should be performed before implementing a full-scale cleanup and are recommended before final remedy selection. Specifically, additional characterization is recommended in the Alaska Real Estate Parking Lot area, where active remediation is proposed for Alternatives GW-2 through GW-5. The purpose of this characterization is to more accurately define the contamination thickness that requires active treatment, and to potentially determine the location of the Bootlegger clay unit. For purposes of this FFS, it is assumed that contamination is present from the water table (approximately 40 feet) to a depth of 70 feet bgs.

7.2 Description of Alternatives

The groundwater alternatives considered in the FFS are discussed in the following sections. The cost estimates for each alternative are provided in Appendix A.

7.2.1 GW-1: No Action

The No Action Alternative is used as a baseline reflecting current conditions without remediation. This alternative is used for comparison with each of the other alternatives.

7.2.2 GW-2: Monitored Natural Attenuation

Alternative GW-2 uses natural processes occurring in groundwater to reduce contaminant concentrations over time (MNA) and LTM to track progress of the MNA and evaluate the remedy's effectiveness. As with the other alternatives, ICs will be used to protect human health until RAOs are reached.

Dilution, adsorption, volatilization, precipitation, complexation, and biological degradation of the contaminants occur in the groundwater. Of these processes, reductive dechlorination (using biological and/or abiotic degradation processes) is usually the most significant degradation process for chlorinated solvents such as PCE and TCE. MNA would allow these processes to continue as they have in the past, without disturbances potentially caused by implementation of active remedial technologies. TCE has been showing to degrade at some sites under aerobic, intrinsic conditions (known as cometabolic degradation) at rates that are slow, but still potentially relevant to long remediation timeframes. However, the primary contaminant at this site is PCE, which is not susceptible to cometabolic degradation.

7.2.2.1 Biological Degradation of PCE

The most important process for the natural biodegradation of the most highly chlorinated solvents (PCE and TCE) is reductive dechlorination. During this process, the chlorinated hydrocarbon is used as an electron acceptor, and a chlorine atom is removed and replaced with a hydrogen atom. In general, reductive dechlorination occurs by sequential dechlorination from PCE to TCE to DCE to VC to ethene. Reductive dechlorination occurs in anaerobic groundwater conditions; the most rapid rates occur under highly reducing (sulfate-reducing and methanogenic) conditions (Wiedemeier, et. al., 1998), although reductive dechlorination has also been documented to occur under nitrate- and iron-reducing conditions. Because chlorinated hydrocarbons are used as electron acceptors during reductive dechlorination, there must be an appropriate source of carbon for microbial growth in order for this process to occur. Potential carbon sources include natural organic matter, fuel hydrocarbons, or other anthropogenic organic compounds.

The geochemical evolution of groundwater is shown in the diagram below. DO is the most thermodynamically favored electron acceptor used by microbes for the biodegradation (oxidation) of organic carbon. During aerobic respiration, DO concentrations decrease in the groundwater. After depletion of DO, anaerobic microbes will use nitrate as an electron acceptor, followed by manganese, iron, sulfate, and finally carbon dioxide (methanogenesis). Each sequential reaction drives the oxidation-reduction potential of the groundwater downward into the range within which reductive dechlorination can occur. PCE and TCE degradation can occur in less reducing (i.e., iron-reducing) groundwater than DCE and vinyl chloride degradation (i.e., sulfate-reducing and methanogenic).

Although reductive dechlorination is the most prominent method for biological degradation of PCE and TCE, the daughter products DCE and VC can be oxidized either anaerobically or aerobically. In fact, the aerobic oxidation rate of VC is actually much faster than the anaerobic reductive dechlorination rate. Therefore, at some sites the optimal remedial technique is reductive dechlorination of PCE and TCE and possibly DCE, followed by downgradient oxidation of VC, and possibly also DCE. Due to the dramatically different geochemical conditions required for reductive dechlorination and aerobic oxidation, combining these two degradation mechanisms in the same area can be difficult.

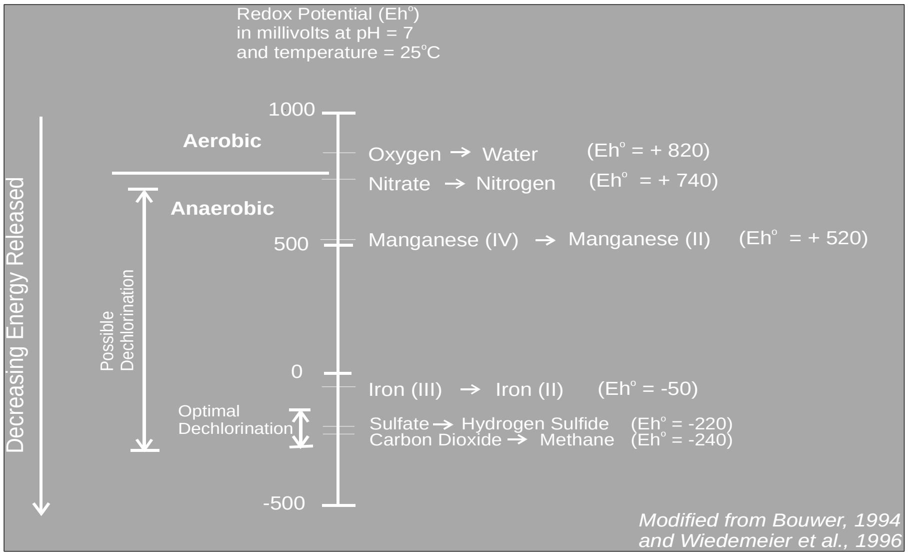

DIAGRAM 1: GEOCHEMICAL EVOLUTION OF GROUNDWATER

7.2.2.2 MNA Considerations

The 1997 through 2012 groundwater sampling data at the site show that there has been some degradation of PCE to TCE at the site but DCE and VC were not detected in the groundwater samples. Samples collected in 2014 to evaluate the potential for MNA (Table 7-1) indicate that biodegradation is not occurring in any appreciable manner because conditions are not anaerobic and therefore do not support dechlorination, and the required microbial populations are not present.

TABLE 7-1: MNA PARAMETER RESULTS

Well ID	MW-10 (background)	MW-5 (source)	MW-6 (source)
Date Sampled	5/15/14	5/14/14	5/13/14
Parameter	**Result**	**Result**	**Result**
Dissolved Oxygen (mg/L)	11.15	3.16	2.97
ORP (mV)	18.4	66.9	160
Iron (µg/L)	11,000	8,700	1,100
Nitrate + Nitrite (mg/L)	4.7	5.5	4.9
Sulfate (mg/L)	29	40	42
Total Organic Carbon (mg/L)	1.8	1.7	1.6
Methane (µg/L)	0.23	0.25	0.026
Ethane (µg/L)	0.0059 J	0.014 J	0.018 J
Ethene (µg/L)	0.015 J	0.013 J	0.015 J
***Dehalococcoides* (#/L)**	-	ND (4 x 10^3)	ND (3 x 10^3)

Key:

#/L	enumeration per liter	ND	not detected at the concentration shown
mg/L	milligrams per liter	ORP	oxidation-reduction potential
µg/L	micrograms per liter		

The presence of TCE degradation products in site groundwater samples is one line of evidence for MNA via reductive dechlorination. Historical groundwater monitoring results (CH2M Hill and E&E, 2008) indicate that very low concentrations of DCE have been detected in samples from three off site monitoring wells: WP-10, WP-11, and WP-12 (max of 0.98 µg/L). The TCE and DCE detections indicate that reductive dechlorination is occurring in some portions of the plume near the former Alaska Native Hospital property.

Overall, data suggest that PCE is being reduced to TCE and DCE in limited amounts. Geochemical parameter data indicate generally aerobic groundwater conditions near the site. Site data do not suggest that MNA (by reductive dechlorination) will be an effective remedy in the short-term, and it appears doubtful whether MNA can adequately treat groundwater contamination at the site in the long-term without some type of biostimulation enhancement.

7.2.2.3 Assumptions for Alternative GW-2

The remediation timeframe would be 30 years, because it is significantly longer than the longest remediation timeframe estimated for an active remedy (12 years), and because the present worth of costs beyond 30 years becomes insignificant. However, the 30-year timeframe is also somewhat arbitrary, because there has not yet been sufficient monitoring to establish a downward trend in groundwater contamination levels.

Seven new monitoring wells would be installed for MNA monitoring. The monitoring network would include the 7 new wells and 11 existing wells (MW-5-10, 4GMW-12-15, MW-28). Quarterly MNA monitoring of 18 monitoring wells would be performed for two years to establish a baseline, followed by semiannual MNA monitoring for three years. This sampling would include VOC contaminants, as well as key parameters for assessing MNA [e.g. dissolved gasses (ethene/ethane/methane), redox parameters (nitrate, sulfate, and ferrous iron), total organic carbon, and water quality parameters). Annual monitoring (including VOC contaminants and MNA parameters) would then be performed for 10 years, followed by annual VOC sampling and MNA parameters every five years for the remaining time (15 years).

The primary risk associated with this alternative is the uncertainty about whether groundwater geochemistry is sufficiently reducing to effectively dechlorinate the PCE, TCE, and DCE to meet ADEC Table C groundwater cleanup levels at the site.

7.2.3 GW-3: In-Situ Chemical Oxidation (ISCO)

In Alternative GW-3, a chemical oxidant would be injected into site groundwater to oxidize the contamination. Several different forms of oxidants have been used for ISCO, including permanganate (MnO_4-), Fenton's hydrogen peroxide (H_2O_2) and ferrous iron (Fe^{+2}) or catalyzed hydrogen peroxide (CHP), ozone (O_3), and persulfate ($S_2O_8^{2-}$). In addition, proprietary oxidants are available. All of these oxidants are considered effective for oxidizing PCE and its degradation products, TCE, DCE, and VC (ITRC, 2005).

7.2.3.1 ISCO Considerations

To treat the groundwater plume, the oxidant would be applied through injection points at a depth interval from the water table to a depth of 70 feet bgs. Permanent injection wells would be used, because it is very likely that multiple injections would be required to treat the residual source area at the site. Once injected, the oxidant would migrate into and through the saturated zone in channels/preferential pathways. While oxidant distribution wouldn't be uniform, the use of a "grid" approach will help overcome uneven distribution. The distribution issues, combined with the fact that the potential exists for a residual source to be present, will likely result in the need to inject the oxidant several times to complete remediation. Bench scale and field pilot tests would be performed to evaluate the radius of influence for the application wells, to determine oxidant dosing requirements, and to refine assumptions regarding the number of applications required.

7.2.3.2 Assumptions for Alternative GW-3

Prior to completing the remedial design, bench-scale testing and a pilot test would be performed for ISCO. The primary goals of the bench-scale testing would be to assess natural oxidant demand, to determine the need for an iron activator, and potentially to evaluate different oxidants. The primary goals of the pilot test would be to assess realistic injection rates and oxidant distribution in the subsurface. As described in Section 4.6, characterization would be required to define the depth of contamination, as well as the total treatment thickness.

Persulfate is the oxidant assumed for Alternative GW-3. Persulfate was selected based on its availability and the presence of iron at the site, which could reduce the amount of activator needed. If ISCO is selected as the groundwater remedy, the actual oxidant selection will be based on bench-scale and pilot-scale testing results. The remediation timeframe is 8 years.

Persulfate will be injected as an aqueous solution into a network of permanent injection wells. Because long screened injection wells can result in uneven vertical distribution, the wells would be screened at two depths, from 40-55 feet bgs, and from 55-70 feet bgs. The wells with pre-packed screens can be installed using direct-push techniques, which will minimize soil cuttings and maximize installation efficiency.

Shallow and deep wells would be installed adjacent to each other as a well pair. Well pairs will be arranged in rows, spaced at 20 feet apart within a given row. Each of the 7 rows of wells will be installed perpendicular to groundwater flow, at a spacing of 30 feet. Wells within a given row will be staggered, such that they are located at the midpoint of the two wells in the next upgradient row. This leads to a total of 104 wells, as shown on Figure 8. Injections would be performed to a radius of influence of 8 feet, which is a volume of approximately 2,200 gallons (based on a 15 feet thickness and porosity during injection of 0.1). This approach will not provide complete inundation of the source area, because injection of an entire pore volume of water is excessive and can result in displacement of contaminants. Instead, this approach will inject approximately 5 to 10% of the pore volume in the source area, per injection.

The aqueous solution would have an injection concentration of 3% persulfate. The injection rate will be up to approximately 2 gallons per minute to help distribute the oxidant within the gravelly sand, and up to 8 wells can be injected simultaneously using a manifold system. The chemical oxidation injections would occur over a 4-year period, with 50% of the total calculated oxidant demand injected each year. This approach will provide a safety factor to account for subsurface heterogeneity, as well as the potential presence of a residual source. The purpose of the 4-year injection period is to optimize injection locations by allowing an assessment of the oxidant distribution between injections and thereby revising the injection geometry, oxidant concentration, and oxidant volume for subsequent injection events.

To calculate the amount of oxidant required, average soil PCE concentration is estimated at 5,000 micrograms per kilograms (µg/kg) and the groundwater PCE concentrations at 1,000 µg/L. The natural oxidant demand is assumed to be 1 gram persulfate oxidant per kg soil, but this will be confirmed based on bench-scale testing (note that if other oxidants are used, the soil oxidant demand may change). The size of the treated area would be 150 feet by 250 feet by 30 feet deep (40 to 70 feet bgs). The average aquifer porosity is estimated at 0.35. The total amount of oxidant required for the contamination was calculated at approximately 101,000 pounds, assuming the density of soil to be 90 pounds per cubic feet (lbs/ft^3) and the weight of water to be 1 kilograms per liter (kg/L). This means that approximately 50,500 lbs of oxidant would be injected during each of the four injection events.

Eight additional wells would be drilled the first year to establish a network to monitor the effectiveness of ISCO. Those 8 wells and an additional 7 would be monitored quarterly during the first year after installation, then semi-annually for the next 2 years. Groundwater would be monitored annually for the remaining 4 years.

7.2.4 GW-4: Enhanced Reductive Dechlorination (ERD)

In Alternative GW-4, a substrate would be injected into site groundwater to enhance the biological degradation processes already occurring to a limited degree at the site. The purpose of the substrate addition is to promote fermentation reactions that then provide an electron donor for the dechlorination reactions. Electron donors are generated by fermentation of non-chlorinated organic substrates, including naturally occurring organic carbon, accidental releases of anthropogenic carbon (fuel hydrocarbons), or introduced substrates such as alcohols, low-molecular-weight fatty acids, carbohydrates (sugars), vegetable oils, and sodium lactate. In addition, proprietary substrates are available.

7.2.4.1 ERD Considerations

To treat the groundwater water plume, the carbon source would be applied through injection points at a depth interval above and into the groundwater and migrate through the saturated zone and downgradient. One consideration for enhanced bioremediation at this site is the ability to drive the groundwater plume to anaerobic conditions and maintain these conditions over time. The limited MNA field parameter results indicate that the site groundwater is generally aerobic, and there are likely significant competing electron acceptors that will need to be reduced before complete PCE reduction to ethene will occur. For ERD, bench studies are likely not needed; a pilot study would be performed to estimate the dosing requirements and evaluate amendment distribution and refine assumptions regarding the number of applications required.

Additionally, *Dhc*, the only known organisms capable of the complete dechlorination of DCE and VC to ethene, has not been found at the site. Although it is possible for DHC to grow to sufficient numbers from amendment additions alone, it is likely that this microbe would need to be introduced at the site once conditions are sufficiently reduced, known as bioaugmentation. Further downgradient of the plume, where petroleum acts as a carbon source, *Dhc* was found in significant numbers. This indicates that the microbe can thrive in a similar environment and may create an active remedial zone in the source area once conditions are reducing.

7.2.4.2 Assumptions for Alternative GW-4

Prior to completing the remedial design at the site, a pilot test would be performed for ERD. The primary goals of the pilot test would be to determine which substrate(s) to inject, assess realistic injection rates, and substrate distribution in the contaminant plume.

The ERD amendment would be injected using the same layout of injection wells as the ISCO alternative – well pairs with screens from 40-55 feet bgs, and 55-70 feet bgs. The wells would be arranged in rows as shown in Figure 8.

For costing purposes, Tersus EDS-ER Emulsified Vegetable Oil (EVO) a proprietary substance available from Tersus, would be the substrate used. However, several EVO products are available, and all would be expected to perform similarly to the Tersus product. An EVO was selected because of its long-term timed release of electron donors that lasts 18-36 months without reinjection. Once the site has been shown to be anaerobic, the *Dhc* organisms would be injected for bioaugementation. The *Dhc* organisms would be released as KB-1® by SiREM, a naturally occurring, non-pathogenic microbial culture that contains *Dhc*. The remediation timeframe would be 10 years.

To calculate the amount of substrate required, average soil PCE concentration is estimated at 5,000 µg/kg and the groundwater PCE concentrations at 1,000 µg/L. The geochemical parameters collected from the 2014 sampling event were used to calculate the competing electron acceptor concentrations: 3 mg/L oxygen, 5 mg/L nitrate, 8 mg/L iron, 40 mg/L sulfate, and 0.1 mg/L methane. Data for manganese were not available and so were assumed at 5 mg/L manganese based on other Alaska sites. The size of the treated area would be 150 feet by 250 feet by 30 feet deep (40 to 70 feet bgs). The average aquifer porosity is estimated at 0.35.

A total requirement of 92,000 pounds of EDS-ER was calculated. The ERD injections would occur every 2 years (Year 3, 5, 7, and 9), with 50% of the total calculated donor demand injected each event, or 46,000 pounds per event. This approach will provide a safety factor to account for subsurface heterogeneity, as well as the potential presence of a residual source.

One bioaugmentation event of 264 liters of KB-1® dechlorinator would be conducted. KB-1® injection would not occur until the aquifer has been driven anaerobic; therefore the bioaugmentation was considered to occur in Year 2. As with the other assumptions in this FFS, selection of the actual microbial consortium for injection would occur after additional characterization and in conjunction with a pilot test.

Eight additional wells will be drilled the first year to establish a network to monitor the effectiveness of ERD. Those 8 wells and an additional 7 would be monitored quarterly during the first two years after installation to determine when the site was anaerobic, then semi-annually for the next 4 years. Groundwater would be monitored annually for the remaining 3 years.

7.2.5 GW-5: Permeable Reactive Barrier (PRB)

Alternative GW-5 involves installing a PRB at the site. A PRB is designed to intercept and remediate the plume as the groundwater migrates downgradient. Various different chemicals can be placed in the barrier depending on the focus of the treatment. Zero-valent iron (ZVI) is commonly used to treat PCE. ZVI is available in various different sizes to change the surface area available for reaction. The PRB could also be a biowall containing microbes and a carbon source to create an anaerobic zone to promote dechlorination like the ERD approach. The PRB could also contain an oxidant like the ISCO approach. PRBs can be placed at various areas throughout or downgradient of the groundwater plume, depending on the focus of the treatment.

In terms of emplacement methods, the most common approach is to trench the PRB, either using conventional excavation or a one-pass trencher. At sites such as this one, where these methods cannot reach the target treatment depth, installation can be performed using soil mixing via large diameter drilled borings, or through emplacement using hydraulic fracturing. At some sites, the ZVI can be entrained in a slurry and injected; in this case the ZVI particles would be "micro-scale ZVI" with a high surface area and fine grain size.

Another option for PRBs is to install rows of conventional injection wells perpendicular to groundwater flow and inject a liquid amendment. This approach is similar to injecting an electron donor or chemical oxidant, except the configuration of injection points is different.

7.2.5.1 Permeable Reactive Barrier Considerations

To treat the groundwater plume, the PRB would be created with a liquid carbon-ZVI amendment to reduce PCE. The sandy gravel and gravelly sands encountered at the site would seem to allow a reasonable injection radius. Depending on the placement of the PRB, the PCE may be degraded to TCE upgradient of the residences and contribute to a TCE vapor intrusion problem. One advantage of the amendment is that it stimulates both abiotic and biological reduction, which can minimize the risk of partial dechlorination (e.g. "stalling"), and can eliminate the need for bioaugmentation. The PRB would have to be placed in a manner to ensure that both PCE and TCE are dechlorinated prior to flow near the residences to limit the vapor intrusion risk. Placing two barriers would aid in ensuring that the RAOs are met. One would be placed across the parking lot in the vicinity of the former dry cleaning facility to treat groundwater as it approached the residences. The other would be placed approximately 100 feet downgradient nearer to the residences, to ensure that complete dechlorination occurs prior to migrating underneath the residences.

The PRB would be most effective if installed to the top of the Bootlegger Cove clay formation to ensure that the entire groundwater vertical extent would be intercepted. In the parking lot area, the entire width of the plume would be transected such that the horizontal extent would be intercepted. However, in the vicinity of the residences, structures and utilities would likely prevent the entire width from transection.

The width, or thickness, of the PRBs would be based on the required residence time of the groundwater within the EHC-L treatment zone. The residence time can be determined during pilot studies by assessing the time required to degrade contaminants and the groundwater flow rate

7.2.5.2 Assumptions for Alternative GW-5

Prior to completing the remedial design, bench-scale testing and a pilot test would be performed for the PRB. The PRB system would perform using hydraulically passive means; no mechanical assistance would be required for the groundwater to flow through the PRB. Like all remedial alternatives, pilot studies and bench scale tests would need to be performed to determine the longevity of the system, which chemicals perform best for treatment, and determine the system hydraulic parameters.

For costing purposes, EHC-L will be the PRB material. Pilot testing would be used to select the actual material for the PRB. The remediation timeframe would be 12 years, and the EHC-L injections would be performed at Years 1, 3, 5, 7, and 9.

The PRB would extend from approximately 40 to 70 feet bgs. The actual depth of the Bootlegger Cove clay formation, which signifies the bottom of the upper aquifer, is unknown. The width/thickness of both PRBs would be similar to the ISCO and ERD alternatives; pairs of shallow/deep injection wells would be installed at 20-foot spacing, with the well pairs being placed in two rows, off-set from each other to help ensure a more uniform distribution, as shown on Figure 9. Each well would be injected to a radius of influence of 12 feet, which is a volume of approximately 2,200 gallons; in this way, the two rows together would ensure a continuous barrier.

The length of the first PRB would be approximately 200 feet to treat the entire width of the plume in the source area. The second would be placed approximately 100 feet downgradient nearer to the residences, between monitoring wells MW-5 and MW-6. The length of this PRB would be 100 approximately feet. It would not intercept the entire plume width due to the presence of structures, but would treat the portion of the plume shown to have the highest concentrations of PCE. This configuration leads to a total of 120 wells, or 60 well pairs, as shown on Figure 9.

To calculate the amount of EHC-L required, average soil PCE concentration is estimated at 5,000 µg/kg and the groundwater PCE concentrations at 1,000 µg/L. The geochemical parameters collected from the 2014 sampling event were used to calculate the competing electron acceptor concentrations: 3 mg/L oxygen, 5 mg/L nitrate, 8 mg/L iron, 40 mg/L sulfate, and 0.1 mg/L methane. Data for manganese were not available and so were assumed at 10 mg/L. The size of the upper PRB would be 200 feet long by 10 feet wide by 30 feet deep (40 to 70 feet bgs) and the size of the lower PRB would be 100 feet long by 10 feet wide. The average aquifer porosity is estimated at 0.35.

A total requirement of 20,000 pounds of EHC-L was calculated. The EHC-L injections would occur every 2 years, with 50% of the total calculated donor demand injected each event. This approach will provide a safety factor to account for subsurface heterogeneity, as well as the potential presence of a residual source. The longevity of the EHC-L is estimated at 2 years. Re-injection of the EHC-L is anticipated to be conducted at Years 3, 5, 7, and 9; an additional injection is assumed compared to ERD and ISCO alternatives because the PRB approach is more passive and does not directly degrade the residual source.

An additional 12 wells would be drilled the first year to establish a network to monitor the effectiveness of the two PRBs. Those 12 wells would be monitored quarterly during the first year after installation, then semi-annually for the remaining 10 years.

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8.0 SUMMARY OF COMPARATIVE ANALYSIS OF ALTERNATIVES

8.1 Evaluation Criteria

The five groundwater remedial alternatives are evaluated against the nine criteria described in 40 Code of Federal Regulations (CFR) 300.430(e)(9)(iii) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and listed below. These criteria are categorized as threshold criteria, balancing criteria, and modifying criteria.

Threshold criteria are standards that an alternative must meet to be eligible for selection as a remedial action. There is little flexibility in meeting the threshold criteria— the alternative must meet them or it is unacceptable. The following are classified as threshold criteria:

- Overall protection of human health and the environment
- Compliance with regulations

Balancing criteria weigh the tradeoffs between alternatives. These criteria represent the standards upon which the detailed evaluation and comparative analysis of alternatives are based. In general, a high rating on one criterion can offset a low rating on another balancing criterion. Five of the nine criteria are considered balancing criteria:

- *Long-term effectiveness and permanence*: This criterion refers to expected residual risk and the ability of a remedy to maintain reliable protection of human health and the environment over time, after the remedy has been completed.
- *Reduction of toxicity, mobility, and volume through treatment*: This criterion evaluates the anticipated performance of the treatment technologies that may be included as part of a remedy.
- *Short-term effectiveness:* This criterion addresses the effectiveness of the remedy during its implementation. It includes the period of time needed to implement the remedy along with any adverse impacts that may be posed to workers, the community, and the environment during construction and operation of the remedy until cleanup levels are achieved.
- *Implementability:* This criterion addresses the technical and administrative feasibility of a remedy from design through construction and operation. Factors such as availability of services and materials, administrative feasibility, and coordination with other governmental entities are also considered.
- *Cost:* This criterion addresses the cost-effectiveness of a remedy based upon design, construction, start-up, monitoring, and maintenance costs.

Modifying criteria evaluate public acceptance and can therefore not be considered in the FFS. The final two criteria are considered modifying criteria:

- Community acceptance
- State/regulatory agency acceptance

8.2 Comparative Analysis of Alternatives

A comparative analysis was performed to identify the advantages and disadvantages of each alternative relative to the other alternatives. The relative performance of each alternative was evaluated with respect to each of the nine criteria. The scoring procedure is discussed in this section.

Threshold criteria are either met or not met; therefore, “yes” and “no” were used as the scores for threshold criteria.

A numerical scoring scheme was used for evaluating the **balancing criteria**. Each alternative was assigned a numerical score between 0 and 5 for each criterion to reflect the expected performance of the alternative. The scores have no independent value; they are only meaningful when compared among the different alternatives. The numerical scores are presented and defined below:

0: Worst (Criterion not satisfied)
1: Poor
2: Below Average
3: Average (Criterion partially satisfied)
4: Above Average
5: Best (Criterion completely satisfied)

All of the criteria except cost were evaluated on a qualitative basis. Cost was evaluated quantitatively by calculating the expected range of costs (within a range of -50% to +100%) and then normalizing the costs to the 0 to 5 scale, with the least expensive alternative receiving a score of 5, and the most expensive alternative receiving a score of 0. The quantitative cost evaluation was performed based on the EPA document entitled A Guide to Developing and Documenting Cost Estimates During the Feasibility Studies (EPA, 2000).

8.3 Comparison of Groundwater Alternatives

The numerical scores of the five groundwater alternatives for the nine criteria are presented in Table 8-1 and discussed in this section. All of the groundwater alternatives assume continued operation of the vapor mitigation system for the duration of the groundwater remedy, i.e., until groundwater RAOs have been met. OM&M costs for continued operation of the vapor mitigation system for the duration of each groundwater remedy are not included in the cost evaluation as they are borne by the landowners.

8.3.1 Threshold Criteria

8.3.1.1 Protection of Human Health and the Environment

Alternative GW-1 (No Action) is not expected to protect human health or the environment and received a score of “no” for this criterion.

The other four alternatives (GW-2 through GW-5) are expected to provide protection of human health and the environment. For all alternatives GW-2 through GW-5, continued operation of the SSD system will mitigate vapor intrusion risk and ICs will be used as necessary to protect human health until groundwater RAOs are met. None of the alternatives are expected to increase plume migration that would allow impacts to the Ship Creek surface water. The monitoring component of all four alternatives GW-2 through GW-5 would be used to monitor any plume migration and thereby ensure protectiveness. Alternatives GW-2 through GW-5 received a score of "yes" for this criterion.

8.3.1.2 Compliance with Regulations

Alternative GW-1 (No Action) is not expected to meet ADEC Table C cleanup levels and received a score of "no" for this criterion.

All four alternatives GW-2 through GW-5 are expected to eventually meet ADEC Table C cleanup levels and therefore received scores of "yes" for this criterion. Alternatives GW-3 (ISCO), GW-4 (ERD), and GW-5 (PRB) are considered to meet cleanup levels to the maximum extent practicable for the site and therefore are considered to be compliant with regulations. There is greater uncertainty to meet compliance with Alternative GW-2 (MNA) due to the lack of dechlorination occurring at the site; this uncertainty is reflected in lower balancing criteria scores discussed below.

8.3.2 Balancing Criteria

8.3.2.1 Long-Term Effectiveness

Alternative GW-1 (No Action) does not provide any groundwater treatment and is not expected to protect human health or the environment in the long-term and received a score of "0" for long-term effectiveness.

Alternatives GW-3 (ISCO) and GW-4 (ERD) are expected to treat most of the groundwater contaminated by PCE to below the ADEC Table C cleanup levels to the maximum extent practicable. For these alternatives, distribution of the oxidant (GW-3) and substrate (GW-4) throughout the source area is considered the most difficult part of the remedy. To the degree that the oxidant and/or substrate can be distributed throughout the plume, both ISCO and ERD are considered effective remedies. Alternative GW-4 is ranked the highest ("4") for long-term effectiveness, because ERD is a robust technology that has shown to exhibit the least amount of contaminant rebound. The only potential impediment is the need for bioaugmentation, but that has been successfully implemented at hundreds of sites across the country. The ISCO alternative (GW-3) is ranked "3.5," because there are no expected impediments other than oxidant distribution, but ISCO sites are more susceptible to rebound following injection. Both ISCO and ERD are considered permanent remedies that are effective in the long-term and not reversible.

The PRB alternative (GW-5) received a score of "3" for long-term effectiveness. The effectiveness of the PRB is expected to be limited by the buildings and structures preventing a barrier across the entire width of the plume. The PCE degradation through the PRB may create daughter products downgradient that would impact indoor air quality in residences. Because the second PRB to treat TCE would not transect the entire plume, all the daughter products may not be treated. The PRB is considered a permanent remedy that is effective in the long-term and not reversible.

The MNA alternative (GW-2) received a score of "1" for long-term effectiveness as a stand-alone remedy. MNA is considered a permanent and effective remedy; however, the effectiveness of reductive dechlorination (the primary biological component of MNA for TCE) is dependent upon anaerobic groundwater conditions and the presence of a carbon source. The analytical evidence suggests that organic carbon content in the aquifer may be a limiting factor for effective and complete degradation of PCE to its non-toxic endpoint, ethene. Also, the analytical evidence suggests that aerobic groundwater conditions are present across most of the site and that the microbe *Dhc* that dechlorinates PCE to ethene is not present at the site. The uncertainty of this alternative is reflected in the long remedial timeframe (30 years) as well as the long-term effectiveness score. It should be noted that if either Alternative GW-4 or GW-5 is selected, then limited MNA would be expected downgradient of the treatment zone. Low concentrations of the injected carbon amendment would eventually migrate downgradient from the source area, and could stimulate some biodegradation.

8.3.2.2 Reduction in Toxicity, Mobility, and Volume through Treatment

Alternative GW-1 (No Action) does not provide any treatment, so it received a score of "0" for reduction in toxicity, mobility, and volume through treatment.

The remaining alternatives are expected to treat most of the groundwater contaminated by PCE to below the ADEC Table C cleanup levels as described below.

- The ISCO alternative (GW-3) is ranked highest ("4") for reduction in toxicity, mobility, and volume through treatment, because it results in the immediate destruction of the contaminant where contacted.
- The ERD alternative (GW-4) received a score of "3.5" for reduction in toxicity, mobility, and volume through treatment. It relies on activity from a microbial community that would need to be added, but as described above, has been successful at hundreds of similar sites. In addition, ERD can create toxic intermediate daughter products (i.e., TCE) whose presence is expected to be of limited duration but must be managed properly. ERD provides the carbon source that is necessary for the reductive dechlorination and therefore has a higher likelihood of effectively treating groundwater than MNA alone.
- The PRB alternative (GW-5) is ranked the next highest at "3" for reduction in toxicity, mobility, and volume through treatment, because it also results in the immediate destruction of the contaminant where contacted. However, due to the limits of the injection area for the PRB, less of the source area would be contacted and it is a significantly more passive remedy than ISCO or ERD.
- The MNA alternative (GW-2) received a score of "1" for this criterion. MNA reduces toxicity, mobility, and volume of contamination; however, its effectiveness is dependent upon anaerobic groundwater conditions and the presence of a carbon source. The analytical evidence suggests that elevated oxygen and low organic carbon

content in the aquifer may be limiting factors for effective and complete degradation of PCE to its non-toxic endpoint, ethene.

8.3.2.3 Short-Term Effectiveness

Alternative GW-1 (No Action) does not provide any treatment. Although the community, workers, and environment do not incur any added risks due to this remedy, there is an infinite time frame until remedy completion. Alternative GW-1 received a score of "0" for short-term effectiveness.

As discussed previously, the short-term effectiveness criterion contains two main components: protection of the community, workers, and environment during remedy implementation, and time until remedy completion. The ranking of alternatives for these two components is nearly opposite each other, resulting in similar overall short-term effectiveness scores. These components are discussed separately below with respect to Alternatives GW-2 through GW-5.

Protection during remedy implementation: Alternative GW-2 (MNA/LTM) is the most protective during implementation, because it involves very little risk due to remedy construction. The only exposure to groundwater contamination would be from groundwater monitoring; this exposure can be readily mitigated by appropriate worker health and safety procedures.

Alternatives GW-3 (ISCO), GW-4 (ERD), and GW-5 (PRB) all have added risks from handling the chemical to be injected. The GW-3 chemical is a reactive oxidant, which has the most risk. The GW-4 chemical is a fatty acid, which is not reactive, but can cause harm to the environment as an oil spill. The GW-5 chemical is a liquid substrate which is similar in risk to ERD amendments. All handling risks can be mitigated by appropriate worker health and safety procedures.

Remedy time frame: The time frame until remedy completion using MNA (GW-2) is uncertain and likely to take many years; a remediation timeframe of 30 years was assumed. Alternative GW-3 (ISCO) is expected to have the shortest timeframe to remedy completion (8 years). Alternative GW-4 (ERD) is estimated at 10 years to remedy completion. Alternative GW-5 (PRB) is estimated at 12 years to remedy completion. The longer time frame assumed for the ERD alternative is based on the need to establish and maintain reducing geochemical conditions and an active microbial community of reductive dechlorinators.

Based on the two components of short-term effectiveness, the overall short-term effectiveness scores for Alternative GW-2 is scored at "2" due to its long duration despite the safety of implementation. Alternatives GW-3, GW-4, and GW-5 are all scored "3.5" because the length of times are similar and balanced by the safety of implementation.

8.3.2.4 Implementability

There are no technical or administrative barriers to implementation of Alternative GW-1 (No Action). Alternative GW-1 received the maximum score of "5" for this criterion.

Alternative GW-2 (MNA) received an implementability score of "4." There are no significant barriers to implementing MNA at this site, but groundwater sampling and analysis is required.

Alternatives GW-3, GW-4, and GW-5 all received scores of "2" for this criterion, because they involve similar implementation tasks such as drilling, injection, monitoring, and logistics. They also all involve obtaining property owner consent and drilling multiple injection wells at the site.

8.3.2.5 Cost

The relative cost scores of the five groundwater alternatives are presented in Table 8-1, and detailed cost spreadsheets are presented in Appendix A. There are no costs associated with Alternative GW-1; therefore, it received the maximum normalized score of "5" for the cost criterion. Alternative GW-4 (ERD) was the most expensive alternative; therefore, it received the minimum normalized score of "0" for this criterion. Excluding the No Action Alternative, Alternative GW-2 (MNA/LTM) was the least expensive and received a cost score of "2.9." Alternatives GW-3 (ISCO) and GW-5 (PRB) received cost scores of "0.2" and "0.6," respectively because they were similar in cost to GW-4 (ISCO).

TABLE 8-1: COST COMPARISON

Remedial Alternative		Cost	Potential Range	
			- 50%	+ 100%
GW-1	No Action	$ 0	-	-
GW-2	MNA	$ 1,080,056	$ 540,028	$ 2,160 ,112
GW-3	ISCO	$ 2,484,874	$ 1,242,437	$ 4,969,748
GW-4	ERD	$ 2,565,548	$ 1,282,774	$ 5,131,097
GW-5	PRB	$ 2,244,750	$ 1,122,375	$ 4,489,500

8.4 Preferred Alternatives

In addition to the individual criteria scores discussed above, there are two comparison tools presented in Table 8-2 that may be used to help select the preferred alternative: the total effectiveness score and the total score. The total effectiveness score reflects the expected overall effectiveness of the alternative; the alternative with the highest score is expected to be the most effective, without regard for implementability and cost. The total score includes cost and implementability considerations along with effectiveness. Therefore, an alternative that is very expensive and/or difficult to implement will have a lower total score compared to an alternative that is less expensive and/or easier to implement.

Based on these scores, Alternatives GW-3 and GW-4 are essentially equal in total score, in effectiveness score, and in cost. They are also similar in implementation of injection wells, monitoring wells, and testing. Determining the preferred alternative should be based on bench scale testing oxidants and amendments to determine whether the assumptions presented in this FFS are reasonable. Data found during testing may show that site conditions favor one alternative.

TABLE 8-2: ALTERNATIVE COMPARISON

Remedial Alternative		Protection of Human Health and Environment	Compliance with ARARs	Long-Term Effectiveness	Reduction in Toxicity, Mobility, and Volume through Treatment	Short-Term Effectiveness	Implementability	Cost Score	Effectiveness Total	Total Score
GW-1	No Action	No	No	0	0	0	5	5	0	10.0
GW-2	MNA	Yes	Yes	1	1	2	4	2.9	1.3	10.9
GW-3	ISCO	Yes	Yes	3.5	4	3.5	2	0.2	3.7	13.2
GW-4	ERD	Yes	Yes	4	3.5	3.5	2	0	3.7	13.0
GW-5	PRB	Yes	Yes	3	3	3.5	2	0.6	3.2	12.1

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TABLES

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Table 1: Historic Groundwater Sampling Results
Focused Feasibility Study
Alaska Real Estate Parking Lot, Anchorage, Alaska

PERMANENT MONITORING WELLS (on-site)

Well ID	Date Installed	Screened Interval	Total Depth	Sample Date	PCE (µg/L)	TCE (µg/L)	cDCE (µg/L)	tDCE (µg/L)	VC (µg/L)
MW-1/EMP-1	1997	Unknown	45	1997	4250				
				Oct-04	2280				
				Apr-05	1490	ND	ND	ND	ND
				Aug-07	154				
				May-14	Well Decommissioned				
EMP-2	1997	Unknown	45	1997	ND				
EMP-3	1997	Unknown	45	1997	ND				
MW-2	2005	35-45	45	Apr-05	70.7	ND	ND	ND	ND
				Aug-07	115				
				Jun-08	180	7.6	**0.20**	ND (0.50)	ND (0.50)
				May-14	Well Decommissioned				
MW-3	2005	35-45	45	Apr-05	1790	ND	ND	ND	ND
				Aug-07	338				
				May-14	Well Decommissioned				
MW-4	2005	40-50	50	Apr-05	372	ND	ND	ND	ND
				Aug-07	25.2				
				May-14	Well Decommissioned				
MW-5	2007	33.5-43.5	50	Aug-07	523	ND	ND	ND	ND
				Jun-08	270	**1.0**	**0.15**	ND (0.50)	ND (0.50)
				Jul-08	290	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)
				May-14	1100	ND (5.5)	ND (10)	ND (10)	ND (3.1)
MW-6	2007	34-44	50	Aug-07	822	ND	ND	ND	ND
				Jun-08	430	**1.7**	ND (0.50)	ND (0.50)	ND (0.50)
				Jul-08	1600	ND (10)	ND (10)	ND (10)	ND (10)
				May-14	1700	ND (5.5)	ND (10)	ND (10)	ND (3.1)
MW-7	2007	35-45	47	Aug-07	5.1	ND	ND	ND	ND
				May-14	18	ND (0.20)	ND (0.20)	ND (0.20)	ND (0.20)
MW-8	2011	38-48	47	May-11	0.24	ND (0.2)	ND (0.2)	ND (0.2)	ND (0.2)
				May-14	0.82	ND (0.20)	ND (0.20)	ND (0.20)	ND (0.20)
MW-9	2011	38-48		May-11	ND (0.2)	ND (0.2)	ND (0.2)	ND (0.2)	ND (0.2)
MW-10	2011	38-48	48	May-11	ND (0.2)	ND (0.2)	ND (0.2)	ND (0.2)	ND (0.2)
MW-11	2011	38-48		May-11	ND (0.2)	ND (0.2)	ND (0.2)	ND (0.2)	ND (0.2)
				May-14	Well destroyed during bldg construction				
4GMW-12	2014	24-29	29	May-14	ND (0.2)	ND (0.2)	ND (0.2)	ND (0.2)	ND (0.2)
4GMW-13	2014	8.5-13.5	13.5	May-14	ND (0.2)	ND (0.2)	ND (0.2)	ND (0.2)	ND (0.2)
4GMW-14	2014	8.5-13.5	13.5	May-14	ND (0.2)	ND (0.2)	**81**	ND (0.2)	**9.8**
4GMW-15	2014	4.5-9.5	9.5	May-14	ND (0.2)	**0.86**	**8.9**	**0.27**	**9.6**

TEMPORARY MONITORING WELLS

Well ID	Date Installed	Screened Interval	Total Depth	Date	PCE (µg/L)	TCE (µg/L)	cDCE (µg/L)	tDCE (µg/L)	VC (µg/L)
SB-1	2008	41-45	45	Jul-08	ND (0.20)	ND (0.20)	ND (0.20)	ND (0.20)	ND (0.20)
SB-2	2008	48-52	52	Jul-08	320	ND (2.0)	ND (2.0)	ND (2.0)	ND (2.0)
WP6	2008	0.66-10.66	10.5	6/10/2008	ND (0.50)	**0.22**	**6.8**	ND (0.50)	7.0
WP8	2008	38-48	48	6/13/2008	140	11	ND (0.50)	ND (0.50)	ND (0.50)
WP9	2008	44.29-54.29	55	6/12/2008	ND (0.50)	ND (0.50)	ND (0.50)	ND (0.50)	ND (0.50)
WP10	2008	38.26-48.26	49	6/11/2008	ND (0.50)	ND (0.50)	**0.12**	ND (0.50)	ND (0.50)
WP11	2008	44.91-54.91	55	6/13/2008	620	11	**0.98**	ND (0.50)	ND (0.50)
WP12	2008	49.34-69.34	70	6/13/2008	420	8.7	**0.76**	ND (0.50)	ND (0.50)
WP13	2008	41-51	51	6/13/2008	ND (0.50)	ND (0.50)	ND (0.50)	ND (0.50)	ND (0.50)
WP14	2008	45.03-55.03	55	6/13/2008	ND (0.50)	ND (0.50)	ND (0.50)	ND (0.50)	ND (0.50)
WP15	2008	45.01-55.01	55	6/11/2008	ND (0.50)	ND (0.50)	ND (0.50)	ND (0.50)	ND (0.50)
BK-01GW	2012	35-45	45	Jul-14	ND (5)	ND (5)			
BH-01GW	2012	37-47	47	Jul-12	8500	6	ND	ND	ND
BH-02GW	2012	38-48	48	Jul-12	540	ND (36)	ND	ND	ND
BH-03GW	2012	40-50	50	Jul-12	7.8	ND (5)	ND (5)	ND (5)	ND (5)
BH-04GW	2012	38-48	48	Jul-12	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)
BH-05GW	2012	38-48	48	Jul-12	1600	ND (100)	ND (100)	ND (100)	ND (100)
BH-06GW	2012	38-48	48	Jul-12	**1.1**	ND (5)	ND (5)	ND (5)	ND (5)
BH-07GW	2012	38-48	48	Jul-12	350	ND (5)	ND (5)	ND (5)	ND (5)
BH-08GW	2012	38-48	48	Jul-12	53	ND (5)	ND (5)	ND (5)	ND (5)
BH-09GW	2012	38-48	48	Jul-12	360	ND (5)	ND (5)	ND (5)	ND (5)
BH-10GW	2012	40-50	50	Jul-12	72	ND (5)	ND (5)	ND (5)	ND (5)
BH-12GW	2012	10-20	20	Jul-12	ND (100)	ND (100)	ND (100)	ND (100)	ND (100)

PERMANENT MONITORING WELLS (off-site)

Well ID	Date Installed	Screened Interval	Total Depth	Date	PCE (µg/L)	TCE (µg/L)	cDCE (µg/L)	tDCE (µg/L)	VC (µg/L)
MW-2 (PENCO)	2007	10-20	20	Jan-07	ND (2)	ND (2)	ND (2)	ND (2)	ND (2)
MWB3 (LP022/ML&P)	Unknown	6-18.5	Unknown	Jun-08	ND (0.50)	**0.26**	**0.48**	ND (0.50)	ND (0.50)
MW9/B9 (LP022/ML&P)	Unknown	4.5-14.5	Unknown	Jun-08	ND (0.50)	**0.45**	**0.69**	ND (0.50)	ND (0.50)
MW12S (LP022/ML&P)	Unknown	4-9	9.5	Jun-08	ND (0.50)	**0.22**	**0.49**	ND (0.50)	ND (0.50)
MW28 (LP133/ML&P)	Unknown	4-9	11	Jun-08	23	18	180	**3.0**	22
MW7/B7 (LP022/ML&P)	Unknown	1.5-17.5	Unknown	Jun-08	**0.81**	**0.42**	**0.29**	ND (0.50)	ND (0.50)
MW24S (LP135/ARRC)	Unknown	3-8	Unknown	Jun-08	ND (0.50)	**0.22**	**1.4**	ND (0.50)	ND (0.50)
DPB24 (LP133/ARRC)	Unknown	Unknown	12	Sep-06	ND (0.5)	ND (0.5)			ND (0.5)
				Jan-07	ND (0.5)	ND (0.5)			ND (0.5)
				May-14	ND (0.20)	ND (0.20)	ND (0.20)	ND (0.20)	ND (0.20)

	PCE (µg/L)	TCE (µg/L)	cDCE (µg/L)	tDCE (µg/L)	VC (µg/L)
Cleanup Levels	5	5	70	100	2

Missing RLs
Greater than cleanup levels
RL greater than cleanup level
NR - not reported
NS - not sampled
Bold - detected below cleanup level

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FIGURES

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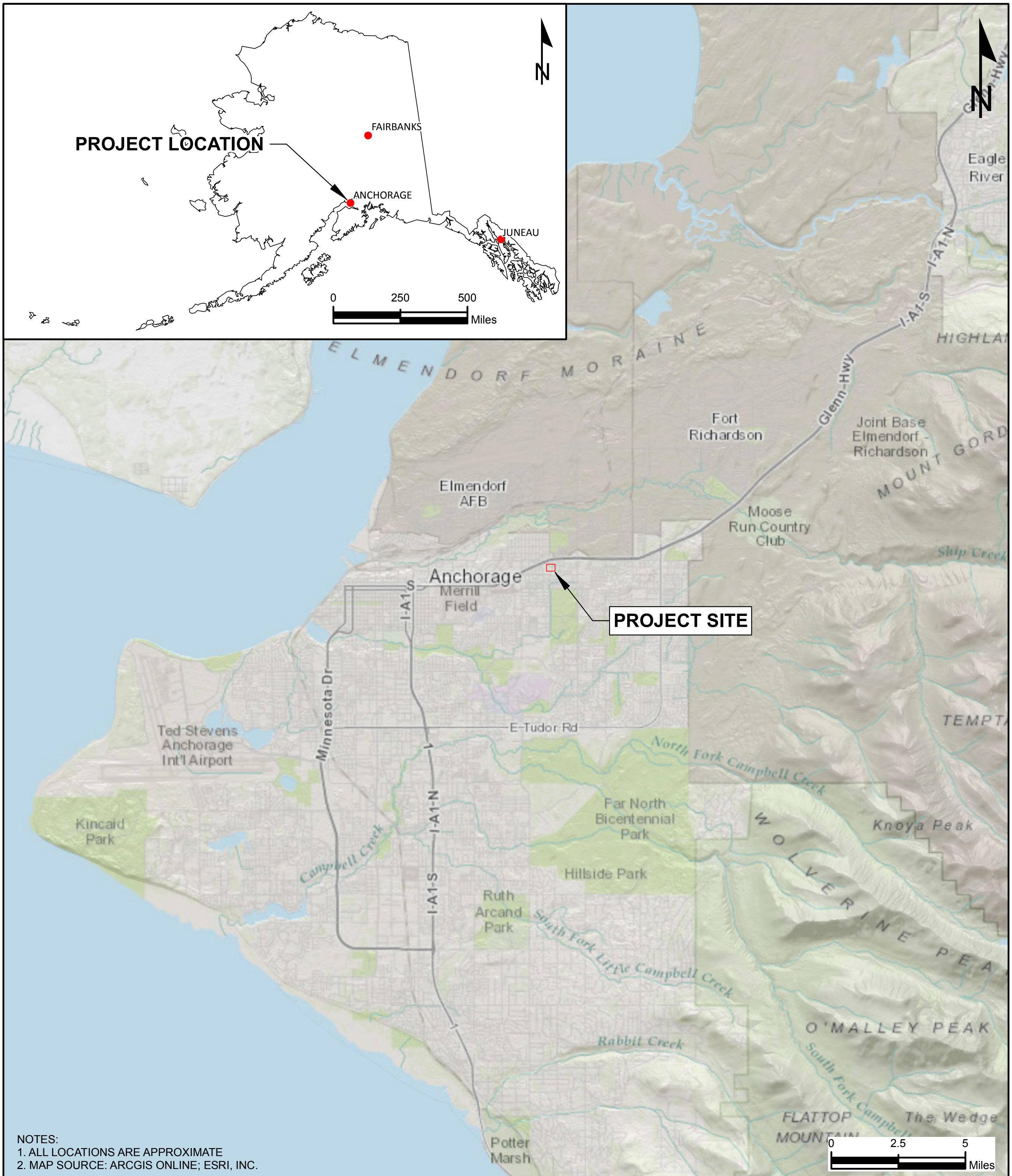


NOTES:
1. ALL LOCATIONS ARE APPROXIMATE
2. MAP SOURCE: ARCGIS ONLINE; ESRI, INC.

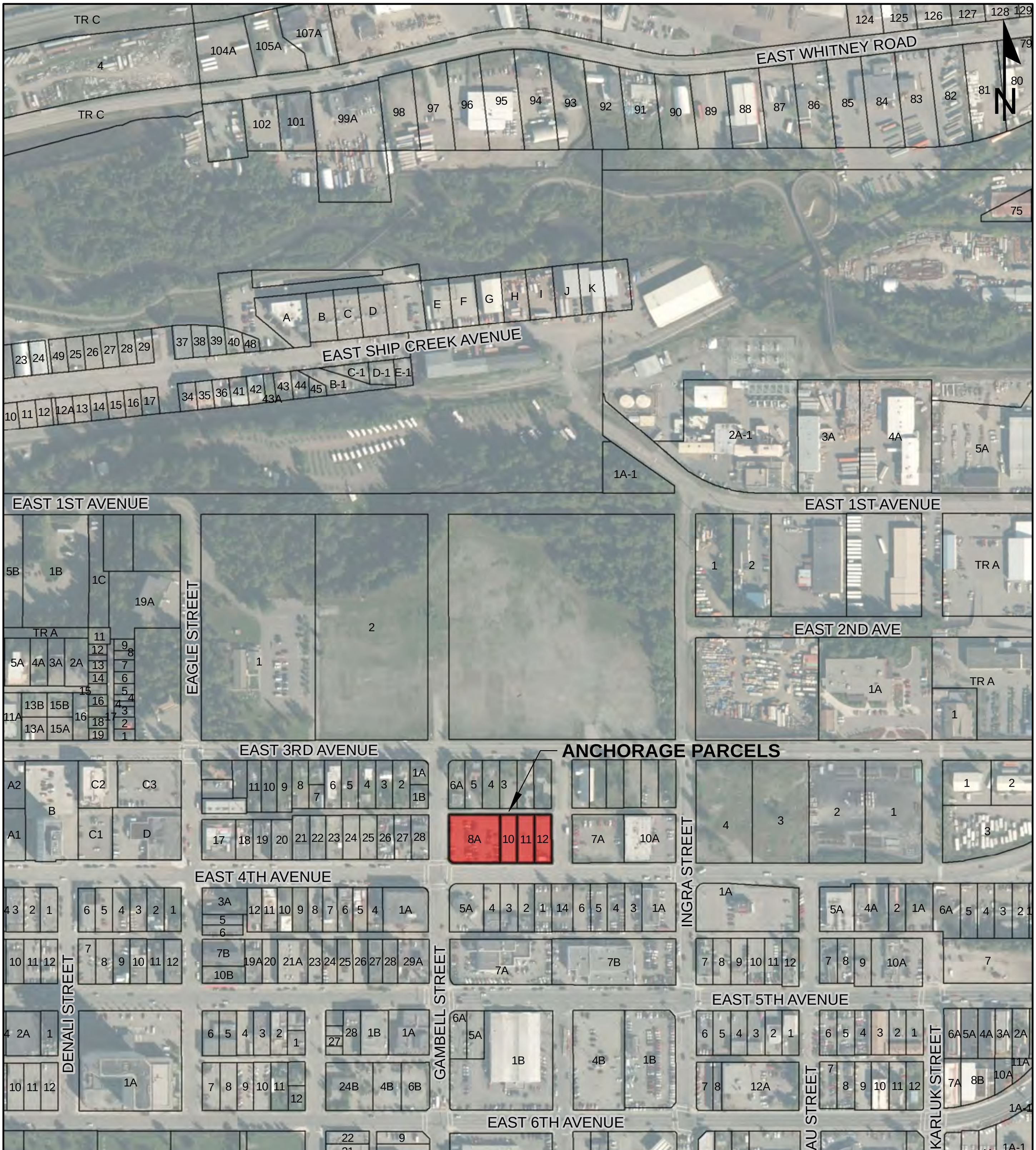
FOCUSED FEASIBILITY STUDY
ALASKA REAL ESTATE PARKING LOT, ANCHORAGE, ALASKA

Ahtna Engineering

STATE AND SITE VICINITY

Project Number: 20266.008	Figure Number: 1
Date: 9/15/2014	
Drafted By: jclous	

Prepared by jclous, 9/15/2014; L:\Anchorage\20266.008_AK_Real_Estate\GIS\MXD\Feasibility_Report\Figure_1_Feasibility_Report.mxd



NOTES:
1. ALL LOCATIONS ARE APPROXIMATE
2. MAP SOURCE: ARCGIS ONLINE; ESRI, INC.

FOCUSED FEASIBILITY STUDY
ALASKA REAL ESTATE PARKING LOT, ANCHORAGE, ALASKA

Ahtna Engineering

ANCHORAGE PARCELS

Project Number: 20266.008	**Figure Number:** 2
Date: 9/15/2014	
Drafted By: jclous	

Prepared by jclous, 9/15/2014; L:\Anchorage\20266.008_AK_Real_Estate\GIS\MXD\Feasibility_Report\Figure_2_Feasibility_Report.mxd

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NOTES:
1. ALL LOCATIONS ARE APPROXIMATE
2. MAP SOURCE: ARCGIS ONLINE; ESRI, INC.

FOCUSED FEASIBILITY STUDY
ALASKA REAL ESTATE PARKING LOT, ANCHORAGE, ALASKA

Ahtna Engineering

SITE MAP

Project Number: 20266.008	Figure Number: 3
Date: 9/15/2014	
Drafted By: jclous	

FOCUSED FEASIBILITY STUDY
ALASKA REAL ESTATE PARKING LOT, ANCHORAGE, ALASKA

Ahtna Engineering

GROUNDWATER PLUME

Project Number: 20266.008	Figure Number: 4
Date: 11/4/2014	
Drafted By: dhickey	

Prepared by dhickey, 11/4/2014; L:\Anchorage\20266.008_AK_Real_Estate\GIS\MXD\Feasibility_Report\Figure_4_Feasibility_Report.mxd

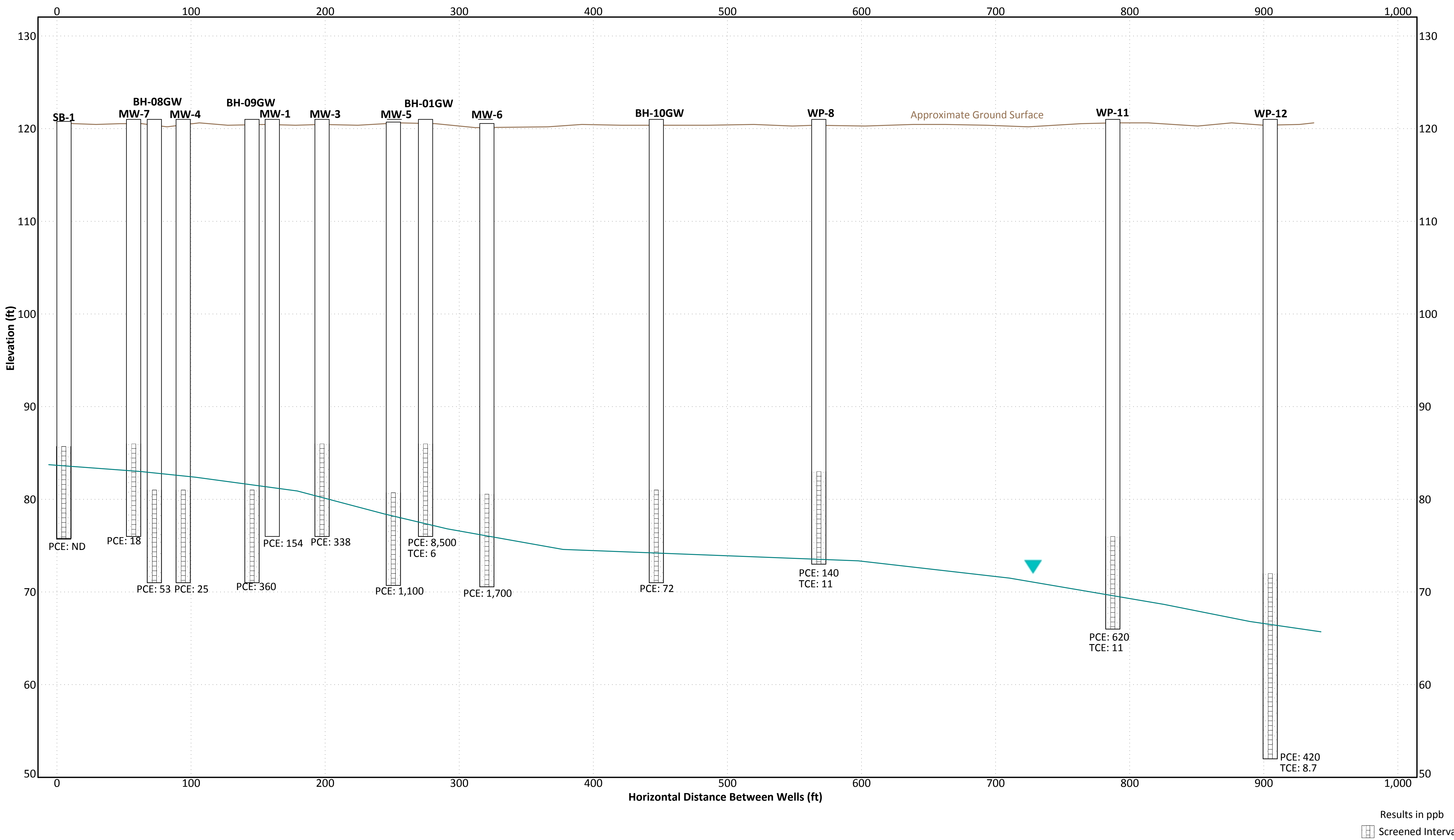
FOCUSED FEASIBILITY STUDY
ALASKA REAL ESTATE PARKING LOT, ANCHORAGE, ALASKA

Ahtna Engineering

SECTION LINES

Project Number: 20266.008
Date: 11/4/2014
Drafted By: dhickey
Figure Number: 5

Prepared by dhickey, 11/4/2014; L:\Anchorage\20266.008_AK_Real_Estate\GIS\MXD\Feasibility_Report\Figure_5_Feasibility_Report.mxd

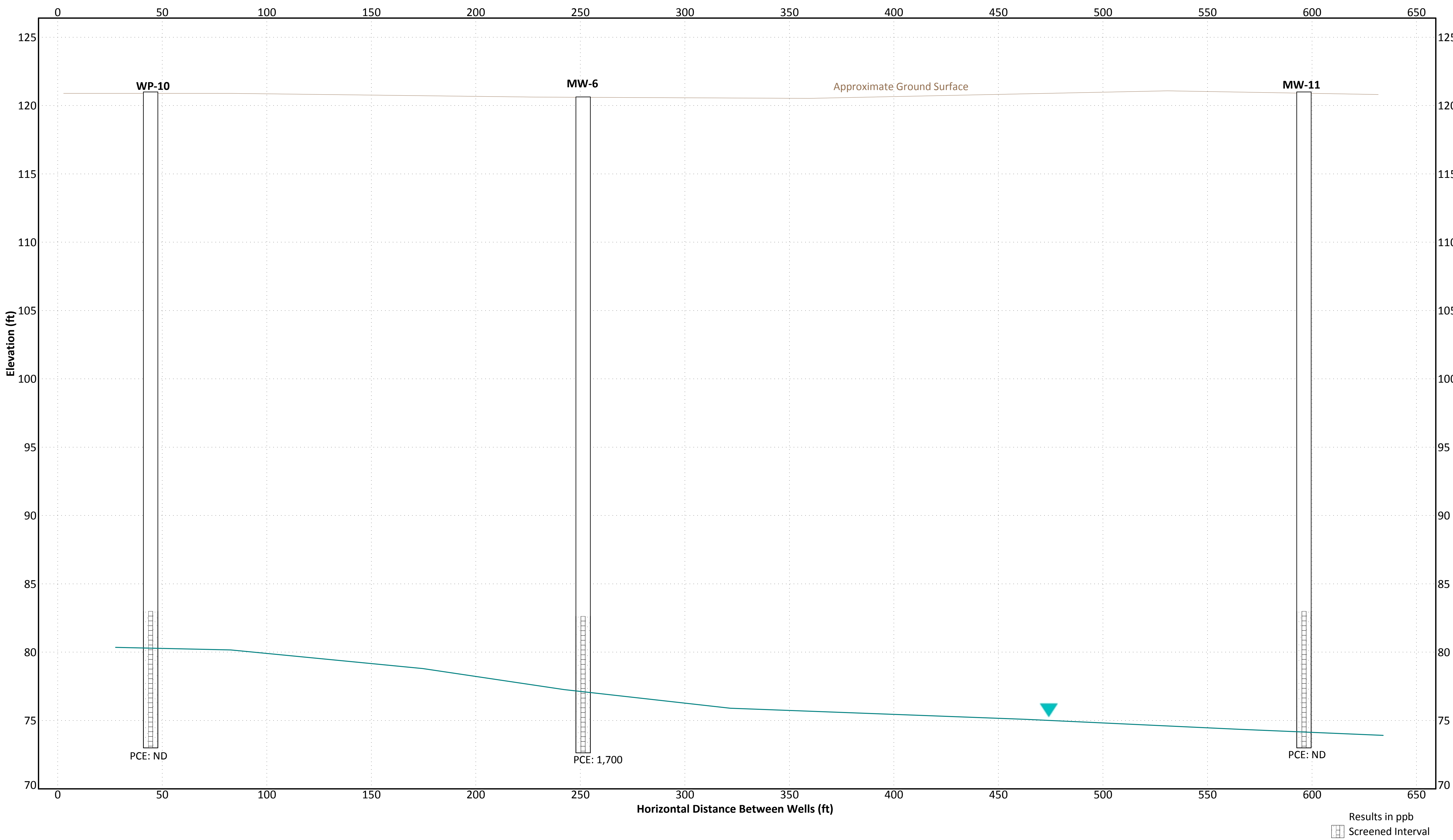


FOCUSED FEASIBILITY STUDY
ALASKA REAL ESTATE PARKING LOT, ANCHORAGE, ALASKA

CROSS SECTION A-A'

Ahtna Engineering

Project Number: 20266.008	Figure Number
Drawn By:	6
Date: 9/13/2014	



FOCUSED FEASIBILITY STUDY
ALASKA REAL ESTATE PARKING LOT, ANCHORAGE, ALASKA

CROSS SECTION B-B'

Ahtna Engineering

Project Number: 20266.008
Drawn By:
Date: 9/13/2014
Figure Number 7

LEGEND

- SHALLOW/DEEP INJECTION PAIRS
- EXISTING MONITORING WELL
- INFERRED PLUME BOUNDARY
- PARCELS

NOTES:
1. ALL LOCATIONS ARE APPROXIMATE
2. MAP SOURCE: ARCGIS ONLINE; ESRI, INC.

FOCUSED FEASIBILITY STUDY
ALASKA REAL ESTATE PARKING LOT, ANCHORAGE, ALASKA

Ahtna Engineering

ISCO/ERD INJECTION AREAS

Project Number: 20266.008	**Figure Number:** 8
Date: 10/1/2014	
Drafted By: jclous	

Document Path: C:\Jesse\Projects\AES\AnchorageFR\Figure 8 Feasibility Reporta.mxd

LEGEND

- SHALLOW/DEEP INJECTION PAIRS
- EXISTING MONITORING WELL
- PARCELS
- INFERRED PLUME BOUNDARY

NOTES:
1. ALL LOCATIONS ARE APPROXIMATE
2. MAP SOURCE: ARCGIS ONLINE; ESRI, INC.

FOCUSED FEASIBILITY STUDY
ALASKA REAL ESTATE PARKING LOT, ANCHORAGE, ALASKA

PRB INSTALLATION AREAS

Ahtna Engineering

Project Number: 20266.008	Figure Number: 9
Date: 10/1/2014	
Drafted By: jclous	

Document Path: C:\Jesse\Projects\AES\AnchorageFRI\Figure 9 Feasibility Reporta.mxd

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APPENDIX A

COST ESTIMATES

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Alternative Cost Summary
Focused Feasibility Study
Alaska Real Estate Parking Lot, Anchorage, Alaska

Remedial Alternatives for Groundwater		**Cost**	**Potential Range (-50%)**	**Potential Range (+100%)**	**Normalized Score**		
Alternative GW-1	No Action	$ -	$ -	$ -	0.00	1.00	**5.0**
Alternative GW-2	Monitored Natural Attenuation (MNA)	$ 1,080,056	$ 540,028	$ 2,160,112	0.42	0.58	**2.9**
Alternative GW-3	In-Situ Chemical Oxidation (ISCO)	$ 2,484,874	$ 1,242,437	$ 4,969,748	0.97	0.03	**0.2**
Alternative GW-4	Enhanced Reductive Dechlorination (ERD)	$ 2,565,548	$ 1,282,774	$ 5,131,097	1.00	0.00	**0**
Alternative GW-5	Permeable Reactive Barrier (PRB)	$ 2,244,750	$ 1,122,375	$ 4,489,500	0.87	0.13	**0.6**

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Alternative GW-2
Monitored Natural Attenuation

Function		Units	Quantity	Cost Per Unit	Total Cost	Total Cost (- 50%)	Total Cost (+ 100%)
Capital Costs							
	Work Plan	hr	60	$85.00	$5,100		
	Installation of monitoring wells (7 wells)	well	7	$4,500.00	$31,500		
	Reporting	hr	80	$85.00	$6,800		
	Transportation and misc. costs	estimate	1	$7,500	$7,500		
Capital Costs Subtotal					**$45,800**	**$22,900**	**$91,600**
Contingency (Bid)		%	1	15%	$6,870		
Contingency (Scope)		%	1	10%	$4,580		
Subtotal					**$57,250**	**$28,625**	**$114,500**
Project Management		%	1	10%	$5,725		
Remedial Design		%	1	10%	$5,725		
Construction Management		%	1	5%	$2,863		
Institutional Control Implementation		estimate	1	$25,000	$25,000		
Capital Costs Total					**$96,563**	**$48,281**	**$193,125**
Quarterly Groundwater Monitoring and Site Inspection; Years 1-2							
	Site inspection/maintenance	hours	20	$85	$1,700		
	Quarterly Groundwater monitoring (18 wells)	well	18	$1,100	$19,800		
	Groundwater analytical costs (18 wells for VOCs and MNA parameters)	sample	20	$350	$7,000		
	Reporting	hours	60	$85	$5,100		
	Transportation and misc. costs	estimate	1	$7,500	$7,500		
	Total Per Quarter				$33,600		
Quarterly Groundwater Monitoring Years 1-2 Subtotal Per Year					**$134,400**		
Contingency (Bid & Scope)		%	1	25%	$33,600		
Project Management		%	1	10%	$13,440		
Technical Support		%	1	20%	$26,880		
Quarterly Monitoring Costs Years 1-2 Total Per Year					**$208,320**	**$104,160**	**$416,640**
Semi-Annual Groundwater Monitoring and Site Inspection; Years 3-5							
	Total cost per event (from above)	event	1	$33,600	$33,600		
Semi-Annual Groundwater Monitoring Years 3-5 Subtotal Per Year					**$67,200**		
Contingency (Bid & Scope)		%	1	25%	$16,800.00		
Project Management		%	1	10%	$6,720		
Technical Support		%	1	20%	$13,440		
Semi-Annual Monitoring Costs Years 3-5 Total per Year					**$104,160**	**$52,080**	**$208,320**
Annual Groundwater Monitoring and Site Inspection; Years 6-15							
	Total cost per event (from above)	event	1	$33,600	$33,600		
Contingency (Bid & Scope)		%	1	25%	$8,400.00		
Project Management		%	1	10%	$3,360		
Technical Support		%	1	20%	$6,720		
Annual Monitoring Costs Years 6-15 Total Per Year					**$52,080**	**$26,040**	**$104,160**
Groundwater Monitoring and Site Inspections Every 5 Years; Years 16-30							
	Total cost per event (from above)	event	1	$33,600	$33,600		
Contingency (Bid & Scope)		%	1	25%	$8,400.00		
Project Management		%	1	10%	$3,360		
Technical Support		%	1	20%	$6,720		
Periodic Monitoring (every 5 years) Costs Years 21-30 per Year					**$52,080**	**$26,040**	**$104,160**
Present Value Analysis							
Total Capital Costs					**$96,563**	**$48,281**	**$193,125**
Quarterly Monitoring Costs Years 1-2 (Present Worth)					**$376,646**	**$188,323**	**$753,293**
Semi-Annual Monitoring Costs Years 3-5 (Present Worth)					**$238,753**	**$119,377**	**$477,507**
Annual Monitoring Costs Years 6-20 (Present Worth)					**$338,198**	**$169,099**	**$676,396**
Periodic O&M Costs Years 21-30 (Present Worth)					**$29,896**	**$14,948**	**$59,792**
Total Present Worth Cost					**$1,080,056**	**$540,028**	**$2,160,112**

Alternative GW-3
In-Situ Chemical Oxidation

Function	Units	Quantity	Cost Per Unit	Total Cost	Total Cost (- 50%)	Total Cost (+ 100%)
Capital Costs						
Bench-Scale Testing/Pilot Study						
Work Plan	hr	80	$85.00	$6,800		
Bench-Scale Testing	estimate	1	$10,000.00	$10,000		
Pilot Testing for ROI, demand, oxidant type	estimate	1	$40,000.00	$40,000		
Pilot Testing Analytical Costs (TOC, TOD, Mn, grain size, metals)	sample	20	$350.00	$7,000		
Reporting and ISCO Design	hr	200	$85.00	$17,000		
Transportation and misc. costs	estimate	1	$7,500	$7,500		
ISCO Injections						
Permitting	estimate	1	$10,000.00	$10,000		
Permanganate chemical	lb	50,500	$1.43	$72,215		
Iron chemical	lb	28,000	$4.00	$112,000		
Chemical delivery to the site	lb	78,500	$0.60	$47,100		
ISCO injection well installation	well	104	$2,800.00	$291,200		
ISCO injection trailer with manifold	estimate	1	$20,000.00	$20,000		
ISCO Injections	day	26	$2,500.00	$65,000		
Soil Disposal	cy	85	$50.00	$4,250		
Installation of Monitoring Wells (8 wells)	well	8	$4,500.00	$36,000		
Installation Reporting	hr	120	$85.00	$10,200		
Capital Costs Subtotal				**$756,265**	**$378,133**	**$1,512,530**
Contingency (Bid)	%	1	15%	$113,440		
Contingency (Scope)	%	1	10%	$75,627		
Subtotal				**$945,331**	**$472,666**	**$1,890,663**
Project Management	%	1	10%	$94,533		
Remedial Design	%	1	10%	$94,533		
Construction Management	%	1	5%	$47,267		
Institutional Control Implementation	estimate	1	$25,000	$25,000		
Capital Costs Total				**$1,206,664**	**$603,332**	**$2,413,328**
ISCO Injection and Monitoring - Year 2						
ISCO Injections						
Permitting	estimate	1	$2,500.00	$2,500		
Permanganate chemical	lb	50,500	$1.43	$72,215		
Iron chemical	lb	28,000	$4.00	$112,000		
Chemical delivery to the site	lb	78,500	$0.60	$47,100		
ISCO Injections	day	26	$2,500.00	$65,000		
Reporting	hours	60	$85	$5,100		
Quarterly Monitoring						
Site inspection/maintenance	hours	20	$85	$1,700		
Quarterly Groundwater monitoring (15 wells)	well	15	$1,100	$16,500		
Groundwater analytical costs (15 wells for VOCs and MNA parameters)	sample	17	$350	$5,950		
Reporting	hours	60	$85	$5,100		
Transportation and misc. costs	estimate	1	$7,500	$7,500		
Total Per Quarter				$36,750		
Injection and Monitoring Year 2 Subtotal Per Year				**$450,915**		
Contingency (Bid & Scope)	%	1	25%	$112,729		
Project Management	%	1	10%	$45,092		
Technical Support	%	1	20%	$90,183		
Injection and Monitoring Costs Year 2 Total Per Year				**$698,918**	**$349,459**	**$1,397,837**
ISCO Injection and Monitoring - Years 3-4						
ISCO Injections - only half of injection wells						
Permitting	estimate	1	$2,500.00	$2,500		
Permanganate chemical	lb	25,250	$1.43	$36,108		
Iron chemical	lb	14,000	$4.00	$56,000		
Chemical delivery to the site	lb	39,250	$0.60	$23,550		
ISCO Injections	day	13	$2,500.00	$32,500		
Reporting	hours	60	$85	$5,100		
Semi-Annual Monitoring						
Site inspection/maintenance	hours	20	$85	$1,700		
Semi-Annual Groundwater monitoring (15 wells)	well	15	$1,100	$16,500		
Groundwater analytical costs (15 wells for VOCs and MNA parameters)	sample	17	$350	$5,950		
Reporting	hours	60	$85	$5,100		
Transportation and misc. costs	estimate	1	$7,500	$7,500		
Total Per Semi-Annual				$36,750		
Injection and Monitoring Years 3-4 Subtotal Per Year				**$229,257.50**		
Contingency (Bid & Scope)	%	1	25%	$57,314		
Project Management	%	1	10%	$22,926		
Technical Support	%	1	20%	$45,852		
Monitoring Costs Years 5-8 Total Per Year				**$355,349**	**$177,675**	**$710,698**
Annual Groundwater Monitoring and Site Inspection; Years 5-8						
Total cost per event (from above)	event	1	$36,750	$36,750		
Contingency (Bid & Scope)	%	1	25%	$9,187.50		
Project Management	%	1	10%	$3,675		
Technical Support	%	1	20%	$7,350		
Annual Monitoring Costs Years 5-8 Total Per Year				**$56,963**	**$28,481**	**$113,925**
Present Value Analysis						
Total Capital Costs				**$1,206,664**	**$603,332**	**$2,413,328**
Injection and Monitoring Costs Year 2 (Present Worth)				**$610,462**	**$305,231**	**$1,220,925**
Injection and Monitoring Costs Years 3-4 (Present Worth)				**$561,165**	**$280,582**	**$1,122,330**
Annual Monitoring Costs Years 5-8 (Present Worth)				**$106,583**	**$53,291**	**$213,165**
Total Present Worth Cost				**$2,484,874**	**$1,242,437**	**$4,969,748**

Alternative GW-4
Enhanced Reductive Dechlorination

Function	Units	Quantity	Cost Per Unit	Total Cost	Total Cost (- 50%)	Total Cost (+ 100%)
Capital Costs						
Pilot Study						
Work Plan	hr	80	$85.00	$6,800		
Pilot Testing for ROI, demand, amendment type	estimate	1	$40,000.00	$40,000		
Pilot Testing Analytical Costs	sample	20	$350.00	$7,000		
Reporting and ERD Design	hr	200	$85.00	$17,000		
Transportation and misc. costs	estimate	1	$7,500	$7,500		
ERD Injections						
Permitting	estimate	1	$10,000.00	$10,000		
EDS-ER Chemical	lb	47,500	$1.75	$83,125		
Chemical delivery	lb	47,500	$0.60	$28,500		
ERD Injection Well Installation	well	104	$2,800.00	$291,200		
ERD Injection trailer with manifold	estimate	1	$20,000.00	$20,000		
ERD injections	day	26	$2,500.00	$65,000		
Soil Disposal	cy	85	$50.00	$4,250		
Installation of monitoring wells	well	8	$4,500.00	$36,000		
Installation Reporting	hr	120	$85.00	$10,200		
Capital Costs Subtotal				**$626,575**	**$313,288**	**$1,253,150**
Contingency (Bid)	%	1	15%	$93,986		
Contingency (Scope)	%	1	10%	$62,658		
Subtotal				**$783,219**	**$391,609**	**$1,566,438**
Project Management	%	1	10%	$78,322		
Remedial Design	%	1	10%	$78,322		
Construction Management	%	1	5%	$39,161		
Institutional Control Implementation	estimate	1	$25,000	$25,000		
Capital Costs Total				**$1,004,023**	**$502,012**	**$2,008,047**
Quarterly Monitoring - Year 2						
Quarterly Monitoring						
Site inspection/maintenance	hours	20	$85	$1,700		
Quarterly Groundwater monitoring (15 wells)	well	15	$1,100	$16,500		
Groundwater analytical costs (15 wells for VOCs and MNA parameters)	sample	17	$350	$5,950		
Reporting	hours	60	$85	$5,100		
Transportation and misc. costs	estimate	1	$7,500	$7,500		
Total Per Quarter				$36,750		
Monitoring Year 2 Subtotal Per Year				**$147,000**		
Contingency (Bid & Scope)	%	1	25%	$91,920		
Project Management	%	1	10%	$36,768		
Technical Support	%	1	20%	$73,536		
Monitoring Costs Year 2 Total Per Year				**$349,224**	**$174,612**	**$698,448**
KB-1 Injection, ERD Injection and Quarterly Monitoring - Year 3						
Injections						
Permitting	estimate	1	$2,500.00	$2,500		
EDS-ER Chemical	lb	46,000	$1.75	$80,500		
EDS-ER Delivery	lb	46,000	$0.60	$27,600		
KB-1 Chemical	liter	264	$125.00	$33,000		
Chemical delivery	liter	264	$20.00	$5,280		
ERD/KB-1 Injections	day	26	$2,500.00	$65,000		
Reporting	hours	80	$85	$6,800		
Quarterly Monitoring						
Site inspection/maintenance	hours	20	$85	$1,700		
Quarterly Groundwater monitoring (15 wells)	well	15	$1,100	$16,500		
Groundwater analytical costs (15 wells for VOCs and MNA parameters)	sample	17	$350	$5,950		
Reporting	hours	60	$85	$5,100		
Transportation and misc. costs	estimate	1	$7,500	$7,500		
Total Per Quarter				$36,750		
Injection and Monitoring Year 3 Subtotal Per Year				**$367,680**		
Contingency (Bid & Scope)	%	1	25%	$91,920		
Project Management	%	1	10%	$36,768		
Technical Support	%	1	20%	$73,536		
Injection and Monitoring Costs Year 3 Total Per Year				**$569,904**	**$284,952**	**$1,139,808**
Semi-Annual Monitoring - Years 4 and 6						
Monitoring						
Total Per Semi-Annual Event (from above)	event	1	$36,750	$36,750		
Semi-Annual Monitoring Years 4 and 6 Subtotal Per Year				**$73,500**		
Contingency (Bid & Scope)	%	1	25%	$18,375		
Project Management	%	1	10%	$7,350		
Technical Support	%	1	20%	$14,700		
Semi-Annual Monitoring Costs Years 4 and 6 Total Per Year				**$113,925**	**$56,963**	**$227,850**
ERD Injection and Semi-Annual Monitoring - Years 5 and 7						
Injections - Only half of injection wells						
Permitting	estimate	1	$2,500.00	$2,500		
EDS-ER Chemical	lb	46,000	$1.75	$80,500		
EDS-ER Delivery	lb	46,000	$0.60	$27,600		
ERD Injections	day	13	$2,500.00	$32,500		
Reporting	hours	80	$85	$6,800		
Semi-Annual Monitoring						
Site inspection/maintenance	hours	20	$85	$1,700		
Semi-Annual Groundwater monitoring (15 wells)	well	15	$1,100	$16,500		
Groundwater analytical costs (15 wells for VOCs and MNA parameters)	sample	17	$350	$5,950		
Reporting	hours	60	$85	$5,100		
Transportation and misc. costs	estimate	1	$7,500	$7,500		
Total Per Event				$36,750		
Injection and Monitoring Years 5 and 7 Subtotal Per Year				**$223,400**		
Contingency (Bid & Scope)	%	1	25%	$91,920		
Project Management	%	1	10%	$36,768		
Technical Support	%	1	20%	$73,536		
Injection and Monitoring Costs Years 5 and 7 Total Per Year				**$425,624**	**$212,812**	**$851,248**
Annual Groundwater Monitoring and Site Inspection; Years 8-10						
Total cost per event (from above)	event	1	$36,750	$36,750		
Contingency (Bid & Scope)	%	1	25%	$9,187.50		
Project Management	%	1	10%	$3,675		
Technical Support	%	1	20%	$7,350		
Annual Monitoring Costs Years 8-10 Total Per Year				**$56,963**	**$28,481**	**$113,925**
Present Value Analysis						
Total Capital Costs				**$1,004,023**	**$502,012**	**$2,008,047**
Monitoring Costs Year 2 (Present Worth)				**$305,026**	**$152,513**	**$610,052**
Injection and Monitoring Costs Year 3 (Present Worth)				**$465,211**	**$232,606**	**$930,423**
Monitoring Costs Years 4 and 6 (Present Worth)				**$162,826**	**$81,413**	**$325,652**
Injection and Monitoring Costs Years 5 and 7 (Present Worth)				**$568,521**	**$284,261**	**$1,137,043**
Annual Monitoring Costs Years 8-10 (Present Worth)				**$59,941**	**$29,970**	**$119,881**
Total Present Worth Cost				**$2,565,548**	**$1,282,774**	**$5,131,097**

Alternative GW-5
Permeable Reactive Barrier

Function		Units	Quantity	Cost Per Unit	Total Cost	Total Cost (- 50%)	Total Cost (+ 100%)
Capital Costs							
	Bench-Scale Testing/Pilot Study						
	Work Plan	hr	80	$85.00	$6,800		
	Bench-Scale Testing	estimate	1	$10,000.00	$10,000		
	Pilot Testing for ROI, demand, amendment type	estimate	1	$40,000.00	$40,000		
	Pilot Testing Analytical Costs	sample	20	$350.00	$7,000		
	Reporting and ERD Design	hr	200	$85.00	$17,000		
	Transportation and misc. costs	estimate	1	$7,500	$7,500		
	PRB Installation						
	Permitting	estimate	1	$10,000.00	$10,000		
	EHC-L Chemical	lb	10,000	$1.58	$15,800		
	Chemical delivery	lb	10,000	$0.60	$6,000		
	PRB Injection Well Installation	well	120	$2,800.00	$336,000		
	PRB Injection trailer with manifold	estimate	1	$20,000.00	$20,000		
	PRB injections	day	30	$2,500.00	$75,000		
	Soil Disposal	cy	45	$50.00	$2,250		
	Installation of monitoring wells	well	12	$4,500.00	$54,000		
	Installation Reporting	hr	120	$85.00	$10,200		
Capital Costs Subtotal					**$617,550**	**$308,775**	**$1,235,100**
Contingency (Bid)		%	1	15%	$92,633		
Contingency (Scope)		%	1	10%	$61,755		
Subtotal					**$771,938**	**$385,969**	**$1,543,875**
Project Management		%	1	10%	$77,194		
Remedial Design		%	1	10%	$77,194		
Construction Management		%	1	5%	$38,597		
Institutional Control Implementation		estimate	1	$25,000	$25,000		
Capital Costs Total					**$989,922**	**$494,961**	**$1,979,844**
Quarterly Monitoring - Year 2							
	Quarterly Monitoring						
	Site inspection/maintenance	hours	20	$85	$1,700		
	Quarterly Groundwater monitoring (12 wells)	well	12	$1,100	$13,200		
	Groundwater analytical costs (12 wells for VOCs and MNA parameters)	sample	14	$350	$4,900		
	Reporting	hours	60	$85	$5,100		
	Transportation and misc. costs	estimate	1	$7,500	$7,500		
	Total Per Quarter				$32,400		
Monitoring Year 2 Subtotal Per Year					**$129,600**		
Contingency (Bid & Scope)		%	1	25%	$42,725		
Project Management		%	1	10%	$17,090		
Technical Support		%	1	20%	$34,180		
Monitoring Costs Year 2 Total Per Year					**$223,595**	**$111,798**	**$447,190**
PRB Injection and Semi-Annual Monitoring - Years 3, 5, 7, 9							
	Injections						
	Permitting	estimate	1	$2,500.00	$2,500		
	EHC-L Chemical	lb	10,000	$1.58	$15,800		
	Chemical delivery	lb	10,000	$0.60	$6,000		
	PRB Injections	day	30	$2,500.00	$75,000		
	Reporting	hours	80	$85	$6,800		
	Semi-Annual Monitoring						
	Site inspection/maintenance	hours	20	$85	$1,700		
	Groundwater monitoring (12 wells)	well	12	$1,100	$13,200		
	Groundwater analytical costs (12 wells for VOCs and MNA parameters)	sample	14	$350	$4,900		
	Reporting	hours	60	$85	$5,100		
	Transportation and misc. costs	estimate	1	$7,500	$7,500		
	Total Per Event				$32,400		
Injection and Monitoring Years 3, 5, 7, 9 Subtotal Per Year					**$170,900**		
Contingency (Bid & Scope)		%	1	25%	$42,725		
Project Management		%	1	10%	$17,090		
Technical Support		%	1	20%	$34,180		
Injection and Monitoring Costs Years 3, 5, 7, 9 Total Per Year					**$264,895**	**$132,448**	**$529,790**
Semi-Annual Monitoring - Years 4, 6, 8, 10-12							
	Monitoring						
	Total Per Semi-Annual Event (from above)	event	1	$32,400	$32,400		
Semi-Annual Monitoring Years 4, 6, 8, 10-12 Subtotal Per Year					**$64,800**		
Contingency (Bid & Scope)		%	1	25%	$16,200		
Project Management		%	1	10%	$6,480		
Technical Support		%	1	20%	$12,960		
Semi-Annual Monitoring Costs Years 4, 6, 8, 10-12 Total Per Year					**$100,440**	**$50,220**	**$200,880**
Present Value Analysis							
Total Capital Costs					**$989,922**	**$494,961**	**$1,979,844**
Monitoring Costs Year 2 (Present Worth)					**$195,297**	**$97,648**	**$390,593**
Injection and Monitoring Costs Years 3, 5, 7, 9 (Present Worth)					**$714,148**	**$357,074**	**$1,428,297**
Monitoring Costs Years 4, 6, 8, 10-12 (Present Worth)					**$345,383**	**$172,692**	**$690,766**
Total Present Worth Cost					**$2,244,750**	**$1,122,375**	**$4,489,500**